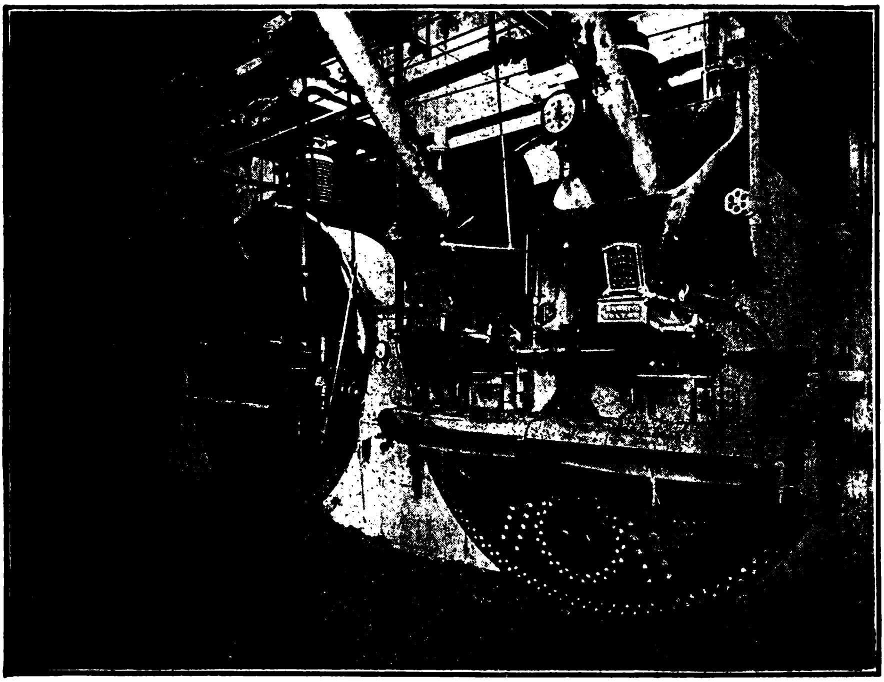
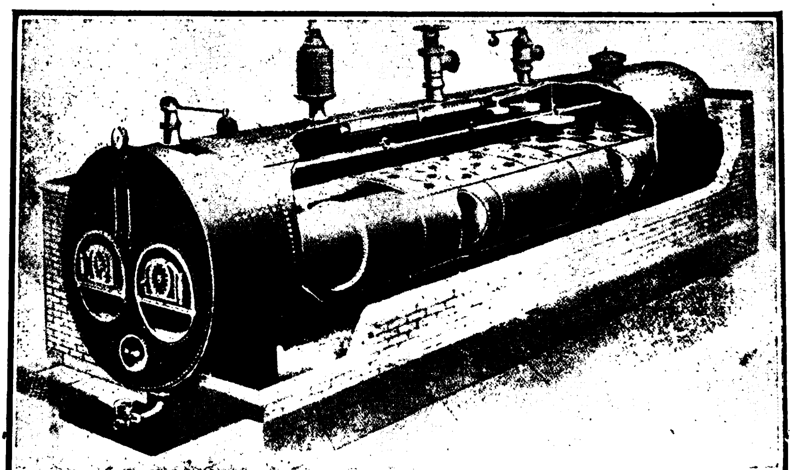


Three Lancashire type boilers fitted with mechanical stokers.



Frontispiece.] Galloway type of Lancashire boiler.

MODERN STEAM BOILERS

THEIR CONSTRUCTION MANAGEMENT AND USE

A PRACTICAL HANDBOOK FOR MARINE AND GENERAL ENGINEERS, STEAM USERS, AND STUDENTS IN ENGINEERING COLLEGES AND TECHNICAL INSTITUTES

BY

ERNEST PULL

MEMBER, INSTITUTE OF MARINE ENGINEERS; ASSOCIATE MEMBER, INSTITUTE OF MECHANICAL ENGINEERS; ENGINEER, ROYAL NAVAL RESERVE.
CERTIFICATED EXTRA FIRST CLASS ENGINEER.
AUTHOR OF "MODERN WORKSHOP PRACTICE," "MODERN MILLING," "SCREW CUTTING FOR ENGINEERS," ETC.
LECTURER AND INSTRUCTOR AT THE LONDON COUNTY COUNCIL SCHOOL OF ENGINEERING AND NAVIGATION, HIGH STREET, POPLAR, E.

WITH ONE HUNDRED AND NINETY-FIVE ILLUSTRATIONS, FIVE PLATES AND THIRTY-THREE TABLES

LONDON
SCOTT, GREENWOOD & SON
(E. GREENWOOD)
8 BROADWAY, LUDGATE, E.C. 4
1918

D. VAN NOSTRAND COMPANY
NEW YORK

PREFACE.

This book has been written in the hope that it will prove of service to Steam Users, Marine and General Engineers, and students in Engineering Colleges.

Boiler Construction and Management, Heat and Fuel, Steam Generation, Feed Water, and allied subjects have been dealt with, and an attempt has been made to illustrate fully and give typical examples of all the principal varieties of boilers at present in everyday use on land and sea. The evaporative power and other important particulars of the various classes of boilers are given, and these should be of use to Steam Users and others desiring such information.

The aim throughout has been to deal with the subject in a practical manner, and to eliminate as much as possible the purely theoretical calculations and problems. Difficult formulæ and higher mathematics have been avoided, in order that the average practical engineer should be able to use the book as a guide and a means of reference.

It is to be understood that the London County Council accept no responsibility for any opinions or conclusions appearing in this book.

E. P.

L.C.C. School of Engineering and Navigation,
High Street, Poplar, London, E. 14,
May, 1918.

CONTENTS.

CHAPTER I.

TEMPERATURE AND HEAT.

CHAPTER II.

STEAM GENERATION.

CHAPTER III.

FUEL AND ITS COMBUSTION.

CHAPTER IV.

BOILER MATERIALS.

CHAPTER V.

BOILER CONSTRUCTION.

CHAPTER VI.

FLUE, SMOKE TUBE, AND MIXED TYPES OF HORIZONTAL BOILER.

CHAPTER VII.

VERTICAL BOILERS.

CHAPTER VIII.

WATER-TUBE BOILERS.

CHAPTER IX.

BOILER MOUNTINGS.

CHAPTER X.

BOILER FEED WATER.

CHAPTER XI.

BOILER DRAUGHT.

CHAPTER XII.

THE MANAGEMENT OF STEAM BOILERS.

TABLES.

LIST OF PLATES.

CHAPTER I.

TEMPERATURE AND HEAT.

THE principles of boiler construction and the economical raising of steam, can be properly understood only by those having a fair knowledge of the laws relating to the properties and nature of heat, and its general effect on water and other substances.

Temperature.—Temperature is the thermal condition of a body which determines the interchange of heat between it and other bodies. The effects of adding heat to a body, unless it is at melting or boiling-point, is to raise its temperature, and the rise in temperature is always accompanied by changes in volume, and it is upon this change in volume that some of the most practical methods of temperature measurement are based.

The temperature of a body is a kind of heat intensity, and is not to be regarded as expressing a quantity of heat, because it would take a great deal less heat energy to raise a piece of lead to a given temperature than would have to be expended in raising an equal mass of water through the same range of temperature. Temperature can be defined as the extent to which a body is capable of communicating heat to other bodies.

Standards of Temperature.—Temperature is measured by certain standards, which were fixed after it had been ascertained that the thermal condition of melting ice and boiling water at normal conditions of pressure were constant; those conditions are universally accepted as standards of temperature.

Absolute Temperature.—Absolute temperature is taken from a point at which heat is believed not to exist, the position of which is about 461° below zero Fahrenheit.

To find the absolute temperature in degrees Fahrenheit it is necessary to add 461° to any temperature shown above zero; thus the absolute temperature of water at boiling-point at atmospheric pressure is 212 + 461, giving an absolute temperature of 673° Fahrenheit.

Thermometry.—The thermometer is an instrument for measuring the intensity of heat by means of the expansive properties of a liquid or gas. The liquid found to be most suitable, and which is

usually employed, is mercury. An ordinary type of thermometer consists of a spherical glass bulb at the end of a fine tube, the bulb being filled, and the tube partly filled, with mercury.

When a change in temperature takes place it is indicated by a rise or fall of the mercury in the tube. A graduated scale, calibrated to show boiling and freezing-points of water, is attached to the thermometer, the interval between the two points being divided into a certain number of divisions. On the centigrade thermometer the distance between the two points is divided into 100°; on the Réaumur thermometer, which is used chiefly in the north-west of Europe, the distance between boiling and freezing-points is divided into 80°, freezing-point being marked 0° and boiling-point 80°; on the Fahrenheit thermometer the distance is divided into 180°, freezing-point being 32° and boiling-point 212°.

All degrees above 0° are termed + degrees and all below − degrees.

Conversions of Temperatures.—Boiling and freezing-points are

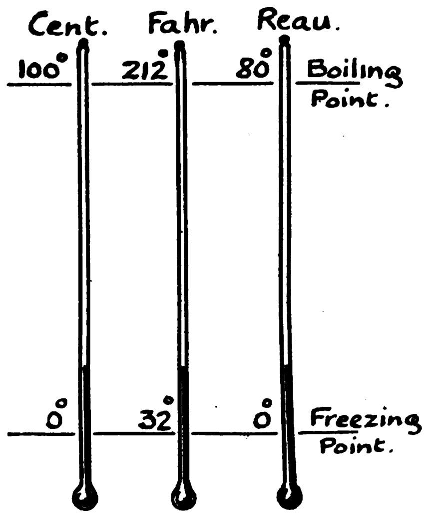


FIG. 1.—Relative readings of thermometers.

shown in comparison at Fig. 1, and can be converted as required by the following formulæ:—

Let T_F = Temperature Fahrenheit
,, T_C = ,, Centigrade
,, T_R = ,, Réaumur

Then $\frac{5}{9}(T_F - 32) = T_C$ Then $\frac{4}{5} T_C = T_R$
,, $\frac{4}{9}(T_F - 32) = T_R$,, $\frac{9}{4} T_R + 32 = T_F$
,, $\frac{9}{5} T_C + 32 = T_F$,, $\frac{5}{4} T_R = T_C$

Engineers' Thermometers.—The application of glass-mercury thermometers to general engineering practice has only become possible by special consideration of working requirements and conditions. A good, reliable, and constant thermometer should have a tube and bulb made from specially selected hard glass, which should be

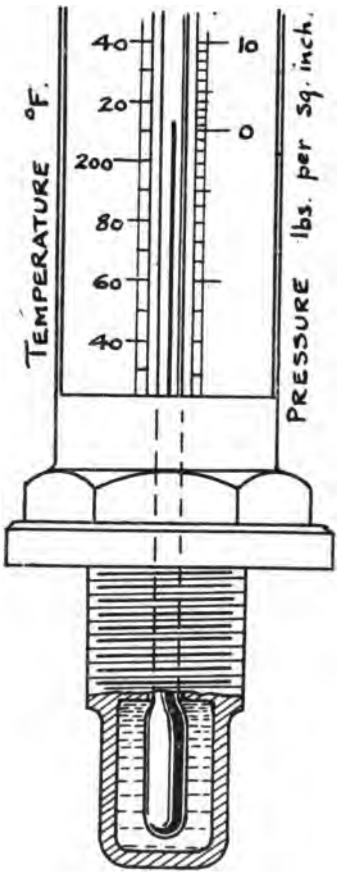


FIG. 2.—Engineer's thermometer.

thoroughly annealed after being filled with the necessary amount of mercury. The scales should be calibrated after the thermometer had aged. A common type of engineers' thermometer is illustrated in Fig. 2. This instrument can be used for obtaining the temperature of steam, the temperature of hot feed water, or for any similar purpose. It is graduated in scales marked in relative pounds pressure per square inch and degrees Fahrenheit. The mercury bulb is en-

cased and protected by a metal cistern formed by the shank of the case, which is filled with mercury so as to bring the heat in contact with the glass bulb of the thermometer. The end of the metallic casing is screwed in order that it may be secured to a steam pipe or boiler in the manner illustrated in Fig. 3. The temperature or pressure may then be read off, as required, without removing the thermometer from its position.

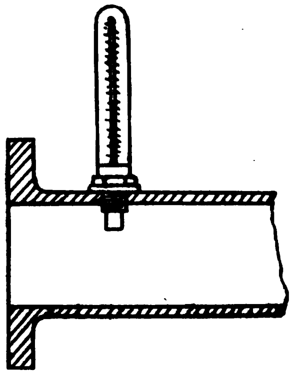


FIG. 3.—Thermometer fitted to a steam pipe.

Pyrometers.—The term pyrometer was originally applied to an instrument in the form of a single metallic bar employed to indicate temperatures above the boiling-point of mercury. It is now applied to any instrument used for a similar purpose. The first pyrometer to come into general use was that invented by Wedgwood about the year 1780, and used by him for testing the heat of his pottery and porcelain furnaces. He found that certain clay compositions, when

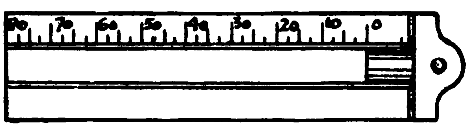


FIG. 4.—Wedgwood pyrometer.

heated, undergo a permanent contraction, and the greater the degree of heat applied to the clay the greater the amount of permanent contraction. To gauge the amount of contraction and thereby ascertain the relative temperature, he prepared a V-shaped plate gauge similar to that illustrated in Fig. 4, and by making clay cylinders of such a size as to just fit at the mark "O" it was possible, by allowing the clay cylinders to attain the temperature of the furnace and then cool, to find the amount of contraction. This being approxi-

mately constant for each separate temperature, it was possible to mark off on the gauge the various temperatures corresponding with the amount of contraction of the clay cylinders.

Many different methods have been devised since Wedgwood

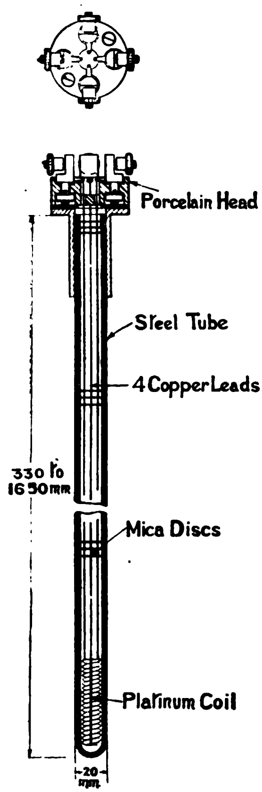


FIG. 5.—Thermo-couple in porcelain tube.

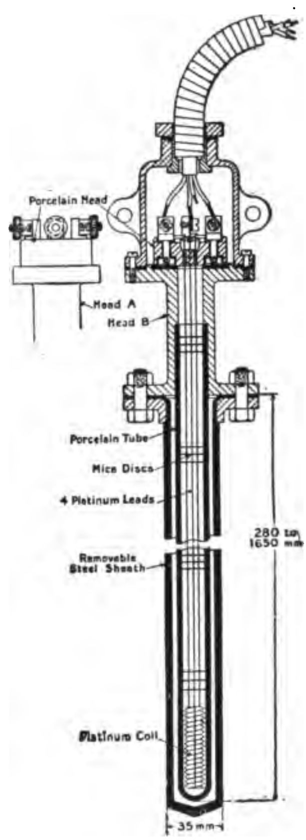


FIG. 6.—Commercial type of thermo-couple.

invented his pyrometer, for measuring high temperatures, among them being:—

1. Expansions of bars of different metals.
2. The fusing-points of metals.
3. Change in resistance to electricity.
4. Generation of electricity.
5. Change in pressure of confined gases.

When a circuit is formed by two wires of different metals being joined together, and the junctions of the two metals are at different

temperatures, an electric current is set up in the circuit, its power or magnitude depending upon the difference in temperature of the hot and cold junctions and the nature of the metals. If a galvanometer or millivoltmeter is introduced between the wires and one junction is kept at a constant temperature, the temperature of the other may be estimated by the amount of deflection on the galvanometer, or if the scale of the galvanometer is graduated in temperature degrees, then the temperature may be read directly.

The pair of wires of different metals used to make the junctions in the circuit is termed the "thermo-couple," and in practice they are frequently of platinum and its alloys in order to resist the high temperatures; it is not usual, however, to run these very expensive

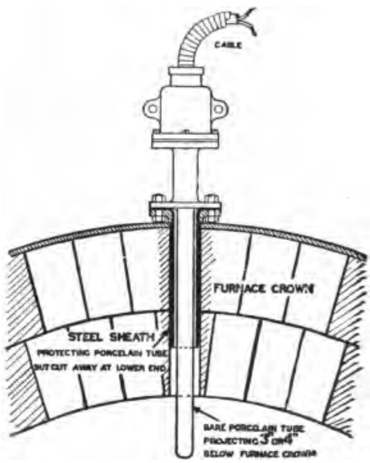


FIG. 7.—Thermo-couple fitted in a furnace crown.

wires all the way to the galvanometer. For this reason a length of copper wire is usually employed to connect from the galvanometer to the thermo-couple.

Thermo-couples.—For temperatures below 800° C., silver and constanton, or iron and constanton thermo-couples are generally used, and these are usually employed when protected by steel tubes.

Constanton is an alloy containing 60 per cent. of copper and 40 per cent. of nickel.

For higher temperatures platinum and platinum-iridium couples are more frequently used, and these are usually protected by quartz or porcelain tubes glazed on the outside to prevent gases coming in contact with, and so deteriorating, the platinum wires. For laboratory work, and in all cases where the temperature is higher than

about 750° C., this porcelain tube is the only protection, and for commercial purposes, where the temperature is below 750° C., a steel protecting sheath is used outside this tube. Fig. 5 illustrates a strong pattern thermo-couple in a porcelain or quartz tube, without the protection of a steel sheath. Fig. 6 shows the type more frequently used for commercial and practical work. This pattern is fitted with a removable steel sheath which can be removed for temperatures above 750° C. The usual method of installing the commercial type of couple in a furnace crown is shown in Fig. 7; in this case the last few inches of the steel sheath are cut away to allow the heat of the furnace gases to come into contact with the couple. Fig. 8 illustrates a steam pipe pattern of thermo-couple,

FIG. 8.—Thermo-couple fitted in a steam pipe.

the tube being bent in order to reduce errors due to the conduction of the heat along the stem.

Temperature Indicators.—Fig. 9 illustrates a thermo-electric recording pyrometer outfit. The thermo-couple is shown mounted in the crown of the furnace, and connected by short lengths of asbestos-covered leads in flexible steel sheathings to a junction box from which lead-covered cable connects to the indicator.

Heat.

In the eighteenth century heat was attributed to the action of some fluid which was called "caloric," and it was supposed to be indestructible. When a substance became hot it was believed that "caloric" was added to it, and on growing colder the "caloric" was believed to leave it.

Rumford's Experiments.—The first experimental observations

on the subject of heat were communicated to the Royal Society in 1798 by Count Rumford. During the operation of boring brass guns at the arsenal at Munich, he was greatly impressed by the amount of heat that was generated by the boring tool, and in order to investigate the matter he obtained a casting of a brass cannon. He surrounded the head of the gun by a wooden box arrangement, in which he placed a known quantity of water. In order to remove as little metal as possible, and to prolong the experiment, he employed a blunt boring tool. This tool was held in a slide rest and fed forward towards the metal by means of a feed screw. Then by

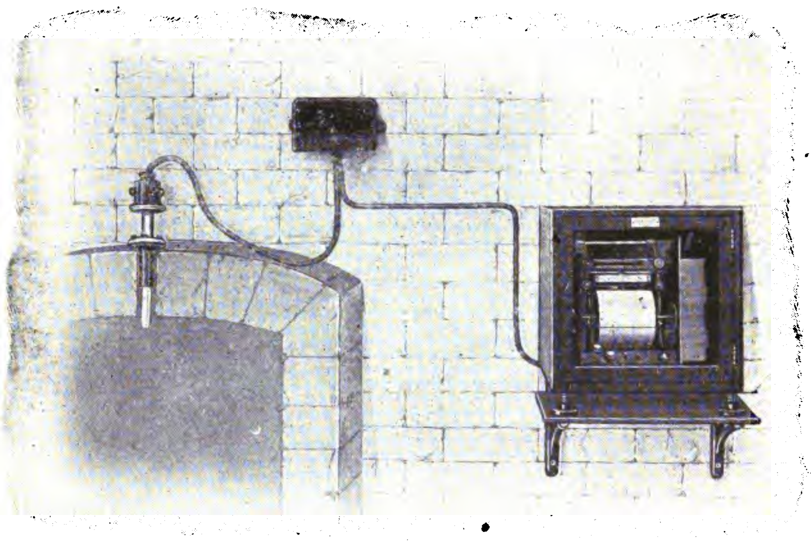


FIG. 9.—Recording thermo-electric pyrometer.

causing the gun to rotate between centres, he found it possible to make the water boil, and also to produce heat continuously while the friction between the tool and the gun was maintained. The caloric theory of the eighteenth century only allowed that the quantity of heat imparted to the water would be limited to the amount of heat present in the gun and boring tool. Count Rumford's experiments proved that the heat supply was inexhaustible.

Joule's Experiments.—The "caloric" theory was not altogether dispelled by Count Rumford's experiments, and many years passed before heat was generally accepted as consisting of a form of energy. The experiments of Dr. Joule of Manchester, carried out between the years 1840 and 1849, went to prove that heat produced by work, or friction, bore a definite ratio to the amount of work expended in

producing the heat, and gave a means of calculating the quantity of work necessary to produce a certain amount of heat. In 1870 the British Association gave Dr. Joule the honour of determining the ratio between work and heat, and after a careful series of investigations and experiments on the friction of water and other substances, he proved that a British Thermal Unit was approximately equal to 772·43 ft.-lbs.; this, by later experiments, was raised to 778 ft.-lbs., and the mechanical equivalent of heat, or the quantity of heat required to raise 1 lb. of water from 39° to 40° Fah., is now taken as the equivalent to the work done in the lifting of 778 lbs. vertically 1 foot. The constant 778 is called Joule's equivalent, and is denoted in formula by the letter J.

British Thermal Unit.—The British thermal unit is the quantity of heat required to raise the temperature of 1 lb. of water at its maximum density through 1° Fah.

Specific Heat.—The specific heat of a substance is the quantity of heat units required to raise its temperature 1° as compared with that necessary to raise the temperature of an equal weight of water 1°.

The specific heats of liquids and solids are practically constant up to a temperature of 212° Fah.

The following table gives the specific heat of various gases, liquids, and solids:—

Table of Specific Heat.

Water	1·000	Coal	0·240
Cast Iron	0·129	Coke	0·200
Steel	0·118	Steam	0·480
Wrought Iron	0·113	Hydrogen	3·404
Copper	0·100	Oxygen	0·218

Transfer of Heat.—The transfer or communication of heat from one body or substance to another may be brought about by three different processes, termed radiation, conduction, and convection.

Radiation.—When an object is placed close to a body having a higher temperature than itself, a rise in temperature will take place, even if a vacuum exists between the objects. This form of heat transference when taking place without the assistance of the other forms of heat transference, is termed radiation, and it represents heat transferred by means of heat waves. Radiant heat is transmitted from a luminous body, and radiant heat and light are different effects of the same thing, both obey the same laws of refraction, reflection, and polarisation. A heated body exposed in a space cooler than itself loses heat to surrounding bodies by radiation, and the amount of heat lost depends upon the temperature of the body and the temperature of the surrounding bodies.

Rate of Heat Transfer by Radiation.—The rate of heat transfer by radiation of heat depends to a great extent on the colour and state of the radiating and absorbing bodies. Hot water takes longer to cool if it is confined in a vessel with smooth metallic surfaces than it would if placed in a rough surfaced vessel; and if a receptacle with a smooth polished surface containing cold water is placed within reach of radiant heat, it will be longer in becoming hot than if the receptacle had a surface which was rough. In these cases the reflecting power of the polished surfaces accounts for the small amount of heat radiated, and for the small amount of heat absorbed.

Relative Radiating Power at 212° Fah.

By the aid of a thermopile and a static galvanometer, the relative quantities of heat radiated from different surfaces have been found. In expressing results the radiating and absorbing power of lamp-black are taken as 100.

Table taken at 212° Fah.

Lamp Black	100	Steel	17
White Lead	100	Polished Brass	7
Glass	90	Polished Copper	7
Indian Ink	85	Silver	3
Platinum	17		

Conduction.—If one end of a bar of metal is placed in a fire and the other end held by hand, it will be found that the bar gets warm, because heat is passing or being conducted from the fire along the rod. The process by which heat passes from one particle of a body to the next is termed conduction, and the body is termed a heat conductor. If the body conducts heat quickly it is said to be a good conductor of heat; if slowly, a bad conductor, and if very slowly, a non-conductor.

The importance of choosing a good or bad conductor will be understood from the following table of approximate relative conductivity of metals and water:—

Copper	100	Iron	16
Brass	40	Silver	10
Zinc	30	Water	0·2

Convection.—Convection is the process by which fluids become heated by actual movement of their particles due to difference in density. When the fluid nearest the source of heat becomes heated, it consequently expands, and, getting lighter, rises, and thereby makes room for the colder liquid, which in turn gets heated and rises.

CHAPTER II.

THE GENERATION OF STEAM.

STEAM is generated in a boiler by the application of heat to some part which is in close contact with the water it contains. The heat by radiation, convection, and conduction raises the temperature of the water to boiling-point and eventually produces steam.

Sensible Heat.—Sensible heat is the heat added to the water during the period in which the temperature is rising, and while no steam is being generated. This heat can be measured by means of the thermometer, and is approximately equal per pound of water to the number of degrees shown on the thermometer.

Latent Heat.—When boiling-point is reached, the heat necessary to convert the water into steam is latent heat, and cannot be measured by the thermometer.

The latent heat of steam at 212° Fah., found by experiment and generally accepted, is ~~966 B.T.U.~~; a more accurate figure is 970·4, but as the former is still used in many formulæ, it has been retained.

Superheat.—Steam heated to a temperature above that which is necessary to make water boil at the given pressure is termed superheated steam.

Total Heat of Steam.—The total heat of steam is taken to be the amount of heat required to raise 1 lb. of water at 32° Fah. to saturated steam of a temperature corresponding to the pressure at which the steam is generated.

The quantity of heat required for this purpose is the sum of the sensible and the latent heat, plus the heat required to generate the steam at a higher temperature than 212° Fah.

The total heat of 1 lb. of steam at 212° Fah. is 1146·6 units, and it increases approximately 0·305 of a unit for every degree rise in temperature. Thus the following formula will give the approximate total heat of saturated steam at any temperature :—

$H = 1146{\cdot}6 + [0{\cdot}305 \times (t^\circ - 212^\circ)]$, t° being the temperature.

Example.—To find the total heat of steam at 358° Fah.

$$\begin{aligned} H &= 1146{\cdot}6 + [0{\cdot}305 \times (358 - 212)] \\ &= 1146{\cdot}6 + (0{\cdot}305 \times 146) = 1190{\cdot}5. \end{aligned}$$

Another formula based on Regnault's experiments is—

$$\text{Total heat} = 1082{\cdot}4 + 0{\cdot}3t^{\circ}.$$

The previous example would give—

$$1082{\cdot}4 + 0{\cdot}3 \times 358 = 1189{\cdot}8.$$

Dryness of Steam.—Steam in contact with the water from which it has been generated usually contains small particles of water mechanically suspended, and therefore steam taken direct from a steam pipe nearly always contains moisture. If steam is tested and found to contain 5 per cent. of moisture, the dryness of the steam is said to be 95 per cent., and out of every 100 lbs. of steam there should be 95 lbs. of dry steam. Dryness of steam is measured by instruments called Steam Calorimeters.

There are three well-known classes of steam calorimeters, namely :—

1. The Separating Calorimeter, which mechanically separates the moisture from the steam.

2. The Throttling or Superheating Calorimeter, in which the steam is allowed to pass through a small orifice and becomes superheated.

3. A combination of 1 and 2.

If the steam be very wet, the throttling calorimeter will not be suitable, because the heat given out by the steam may not be sufficient to convert all the moisture present into steam.

The steam generated by an ordinary boiler would only have a moderate amount of moisture present, and for such tests the throttling calorimeter is very suitable.

The calorimeter illustrated at Fig. 10, is a combination of the separating and throttling type, being fitted with a separating chamber and a throttling orifice. When desired, the separating chamber and throttling calorimeter may be used separately.

The test with the separating calorimeter for moisture is very simple ; first steam should be allowed to blow through for some time to warm the instrument, otherwise, as a result of initial condensation, a quantity of water will accumulate. After passing through the calorimeter the steam should be condensed. This is easily effected by passing it through a coil immersed in cold water, taking care that the length of coil is sufficient to condense all the steam. The steam thus condensed must then be carefully weighed.

Another method is simply to pass the steam into a small tank filled with water. In this case, however, the weight and temperature of the water in the tank must be taken before and after the steam is passed into it.

Suppose a coil is to be used for condensing the steam, the calculations will be as follows :—

Let W_1 be weight of condensed steam which represents weight of dry steam.

Let W_2 be weight of water in separating chamber D which represents weight of moisture.

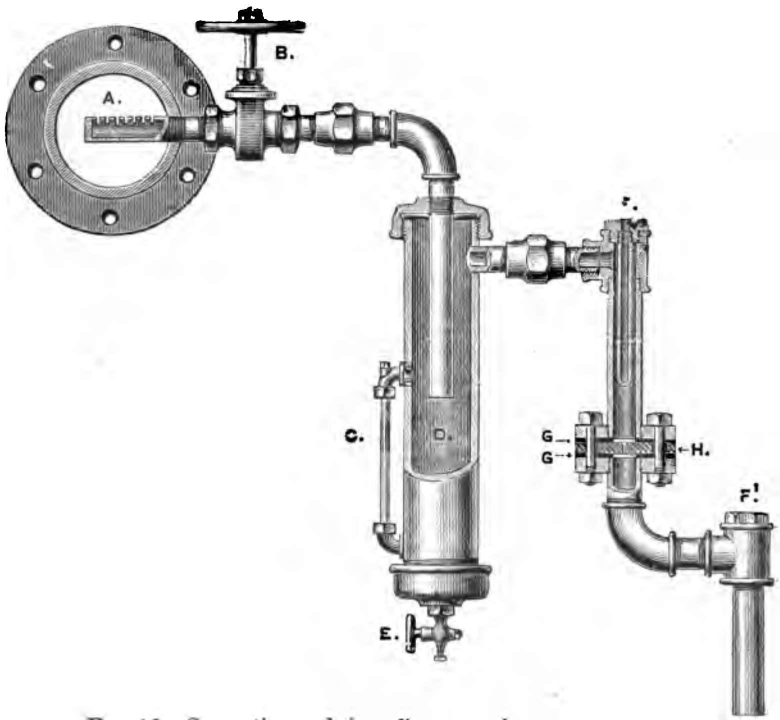


FIG. 10.—Separating and throttling type of steam calorimeter.

Then $W_1 + W_2$ = total weight of steam used.

Let x = "Dryness Fraction" of steam.

$$\text{Then } x = \frac{W_1}{W_1 + W_2}.$$

As an example, when steam is condensed in a coil—

Let W_1 = 2·1 lbs.

W_2 = 0·37 lbs.

$$\text{Then } x = \frac{2{\cdot}1}{2{\cdot}1 + {\cdot}37} = {\cdot}85, \text{ or nearly 85 per cent.}$$

The moisture present is about 15 per cent.

Calculations with Throttling Calorimeter.

This method is not so simple as in the case of the separating calorimeter.

Let t = temperature observed at F^1.
t_1 = " " F.
t_2 = temperature of saturated steam in F which may be taken at 216·3° Fah., corresponding to an absolute pressure of 16 lbs. per sq. inch.
Let H_2 = total heat per lb. for saturated steam corresponding to t_2.
x = Dryness fraction.
L = Latent heat per lb. corresponding to temperature t for dry steam.
Then xL = Latent heat per lb. corresponding to temperature t for wet steam being tested.
Let h = Sensible heat per lb. corresponding to temperature t.
Let H = Total heat per lb. corresponding to temperature t for wet steam being tested.

$$H = h + xL.$$

Then $$H = h + xL = H_2 + \cdot 48(t_1 - t_2).$$

Whence $$x = \frac{H_2 + \cdot 48(t_1 - t_2) - h}{L}.$$

0·48 is the specific heat of steam which is commonly taken as being constant.

In making a test it is only necessary to observe the temperature at F and F^1.

For example:—

Let t = 338° Fah., corresponding to an absolute pressure of 115·1 lbs. per sq. inch.
t_1 = 250° Fah.
t_2 = 216·3° Fah.

Then from steam tables, 32° Fah. reckoned as zero—

H_2 = 1147·9 British Thermal Units
L = 876·3 " " "
h = 308·7 " " "

$$x = \frac{1147 \cdot 9 + \cdot 48(250 - 216 \cdot 3) - 308 \cdot 7}{876 \cdot 3} = 0 \cdot 976 = 97\tfrac{1}{2} \text{ per cent.}$$

i.e. 2½ per cent. of moisture occurs in the steam.

When the steam is first passed through the separating chamber

and then through the throttling calorimeter, the amounts of priming moisture thus obtained are to be added together.

Thus in the example given :—

The amount of water collected from separating chamber	= 15	per cent.
The amount of moisture collected by the throttling calorimeter	= $2\frac{1}{2}$	,,
Total amount of moisture present in steam .	= $17\frac{1}{2}$	,,

Superheated Steam.

The addition of heat to dry saturated steam, not in contact with the water from which it was generated, causes it to rise in temperature and expand. If it is permitted to expand its pressure will remain constant, the pressure only increasing when expansion is stopped.

In boiler practice the superheater is generally an integral part of the boiler, and thus the pressure of the steam is approximately the same as that shown on the boiler pressure gauge.

The volume of superheated steam is greater than saturated steam of the same pressure. The volume of the latter can be obtained from steam tables, and the volume of the former can be approximately determined from the equation—

$$PV = 93{\cdot}5T - 971P^{\frac{1}{4}},$$

where P = pressure in lbs. per sq. foot.
V = volume of 1 lb. in cub. foot.
T = absolute temperature in degs. Fah.

Specific Heat.—The specific heat of superheated steam at constant pressure is uncertain; according to some authorities, at temperatures between 230° Fah. and 246° Fah. it is 0·4317, and between 295° Fah. and 310° Fah. it is 0·648. For most practical purposes 0·48 is taken as its specific heat.

Heat Required to Superheat Steam.—The heat required to superheat dry saturated steam can be determined approximately thus :—

Let T = temperature of superheated steam.
t = temperature of saturated steam.

$$\text{Then heat} = (T - t) \times 0{\cdot}48 \text{ B.T.U. per lb.}$$

Example.—Find the heat required to superheat 1 lb. of steam to 470° Fah. at 150 lbs. absolute pressure.

From steam tables we find the temperature of steam at 150 lbs. pressure to be 358·3° Fah. Then (470 − 358·3) × 0·48 = 53·6 B.T.U.

Total Heat of Superheated Steam.—The total heat of superheated steam is the heat required to superheat to the desired temperature, plus the total heat of dry saturated steam above 32° Fah., and at the superheated pressure.

The total heat in the previous example would be 53·6 plus the total heat of saturated steam at 150 absolute, which, from steam tables, is 1191·2, giving $53 \cdot 6 + 1191 \cdot 2 = 1244 \cdot 8$ B.T.U.

The total heat per lb. of superheated steam can be calculated approximately from—

$$1082 + 0 \cdot 3t + 0 \cdot 48(T - t) = \text{total heat.}$$

Boiling-point.—The boiling-point of water corresponds to the temperature at which ebullition and evaporation into steam begins, and depends upon the pressure in the vessel in which the water is being boiled.

Water heated to boiling-point in a vessel free from pressure commences to give off steam at a temperature of 70° Fah. As the pressure rises, due to the formation of steam, so the boiling-point rises, but not in proportion. The steam when generated starts to exert pressure on the surface of the water, and tends to prevent the formation of vapour from the steam bubbles.

The boiling-point of water under normal conditions varies with the atmospheric pressure; with the barometer at 27½ inches it is 208·6° Fah., and at 31 inches it is 213·6° Fah. Fresh water commences to boil at 212° Fah. under an atmospheric pressure of 14·7 lbs. per sq. inch.

Temperature and Pressure.

Various empirical formulæ are used to find the relative temperature of steam for various pressures, but no accurate simple laws are known to connect pressure and temperature.

Experiment has proved that pressure and temperature are not simply proportional. When the pressure of steam is increased the temperature rises, but not at the same rate. The most practical and reliable method of obtaining the temperature of steam at a given pressure is to refer to a table giving the properties of steam.

Gauge Pressure.

When steam is generated in a closed vessel, the water and steam cannot be under the influence of the atmosphere, and therefore the pressure shown by the boiler steam pressure gauge, which measures pressures above the atmosphere, indicates a pressure which differs

from the absolute pressure by an amount equal to atmospheric pressure. For practical purposes atmospheric pressure is taken as 15 lbs. per sq. inch, and therefore the absolute pressure of steam in a boiler is 15 lbs. greater than that shown by the pressure gauge.

A steam pressure gauge which gives readings in Fahrenheit and

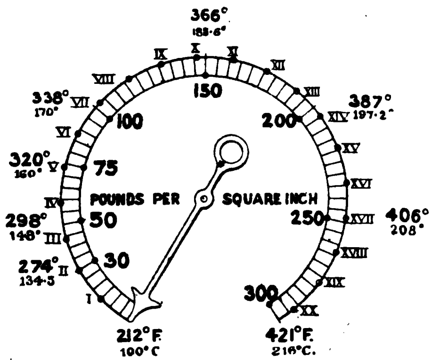


FIG. 11.—Diagram showing relative boiler pressure and temperature.

centigrade is shown in Fig. 11. The atmospheres are indicated by Roman numerals, centigrade by means of figures in light type.

Properties of Steam.

The table of properties of steam on page 18 will be found to give the following important information :—

1. Absolute pressure in lbs. per sq. inch.
2. Inches of mercury.
3. Temperature or boiling-point in degrees.
4. Total heat above 32° Fah.
5. Latent heat above 32° Fah.
6. Heat of water above 32° Fah.
7. Cubic feet of steam from 1 cub. foot of water.
8. Cubic feet per lb.

These tables are based on Renault's experiments, published in 1847. A more accurate set of tables, calculated by Dr. Mollier from the results of the experiments and researches of Professor Callendar, can be found in Sir J. A. Ewing's book, "The Steam Engine and other Heat Engines".

The older table has been purposely used, because of the doubt which still exists as to the accuracy of these tables, and because Renault's experiments are still commonly used as the basis of several empirical equations.

Steam Tables.

PROPERTIES OF SATURATED STEAM.

Absolute Pressure in Lbs. per Sq. Inch.	Inches of Mercury.	Temperature or Boiling-point in Degrees F.	Total Heat above 32° F.	Latent Heat above 32° F.	Heat of Water above 32° F.	Cubic Feet of Steam from 1 Cub. Ft. of Water.	Cubic Feet per Lb.
1	2·036	102·1	1113·1	1044·7	68·4	20582	331·8
2	4·071	126·3	1120·5	1027·3	93·2	10721	172·9
3	6·107	141·6	1125·2	1016·4	108·8	7322	118·1
4	8·142	153·1	1128·7	1008·1	120·6	5583	90·0
5	10·178	162·3	1131·5	1001·5	130·0	4527	73·0
6	12·213	170·2	1133·9	995·8	138·1	3813	61·5
7	14·249	176·9	1135·9	991·0	144·9	3298	53·2
8	16·284	182·9	1137·7	986·7	151·0	2909	46·9
9	18·320	188·3	1139·4	982·8	156·6	2604	42·0
10	20·355	193·3	1140·9	978·2	162·7	2358	38·0
11	22·391	197·8	1142·3	976·0	166·3	2157	34·8
12	24·426	202·0	1143·6	973·0	170·6	1986	32·0
13	26·462	205·9	1144·7	970·2	174·5	1842	29·7
14	28·497	209·6	1145·9	967·5	178·4	1720	27·7
14·7	29·922	212·0	1146·6	965·8	180·8	1642	26·5
15	30·533	213·1	1146·9	965·0	181·9	1610	26·0
16	32·568	216·3	1147·9	962·7	185·2	1515	24·4
17	34·604	219·6	1148·9	946·4	188·5	1431	23·1
18	36·639	222·4	1149·8	958·3	191·5	1357	21·9
19	38·675	225·3	1150·7	956·3	194·4	1290	20·8
20	40·710	228·0	1151·5	954·3	197·2	1229	19·8
21	42·746	230·6	1152·3	952·5	199·8	1174	18·9
22	44·781	233·1	1153·0	950·7	202·3	1123	18·1
23	46·817	235·5	1153·8	948·9	204·9	1075	17·3
24	48·852	237·8	1154·5	947·3	207·2	1036	16·7
25	50·888	240·1	1155·2	945·6	209·6	996	16·1
30	61·065	250·4	1158·3	938·2	221·1	838	13·5
35	71·243	259·3	1161·0	931·9	229·1	726	11·7
40	81·420	267·3	1163·5	926·2	237·3	640	10·3
45	91·598	274·4	1165·6	921·0	244·6	572	9·2
50	101·78	281·0	1167·6	916·3	251·3	518	8·4
55	111·95	287·1	1169·5	911·9	257·6	474	7·6
60	122·13	292·7	1171·2	907·9	263·3	437	7·0
65	132·31	298·0	1172·8	904·1	268·7	405	6·5
70	142·49	302·9	1174·3	900·6	273·7	378	6·1
75	152·66	307·5	1175·7	897·3	278·4	353	5·7
80	162·84	312·0	1177·1	894·0	283·1	333	5·4
85	173·02	316·1	1178·3	891·1	287·2	314	5·1
90	183·20	320·2	1179·6	888·1	291·5	298	4·8
95	193·37	324·1	1180·8	885·3	295·5	283	4·6
100	203·55	327·9	1181·9	882·6	299·3	270	4·4
110	223·91	334·6	1184·0	877·8	306·2	247	4·0
120	244·26	341·1	1185·9	873·1	312·8	227	3·7
130	264·62	347·2	1187·8	868·8	319·0	211	3·4
140	284·97	352·9	1189·5	864·7	324·8	197	3·2
150	305·33	358·3	1191·2	860·8	330·4	184	3·0
160	325·68	363·4	1192·7	857·1	335·6	174	2·8
170	346·04	368·2	1194·2	853·7	340·5	164	2·6
180	366·39	372·9	1195·6	850·3	345·3	155	2·5
190	386·75	377·5	1197·0	847·0	350·0	148	2·4
200	407·10	381·7	1198·3	844·0	354·3	141	2·3
250	508·88	401·1	1204·2	831·0	373·2	114	1·8
300	610·65	417·5	1209·2	818·3	390·9	96	1·5
350	712·43	430·1	1213·1	809·2	403·9	83	1·3
400	814·20	444·9	1217·6	798·6	419·0	73	1·2

Factors of Evaporation.

The evaporative power of a boiler is usually given in terms of the equivalent number of lbs. of water evaporated "*from and at a temperature of* 212° *Fah.*" This method is useful for the purpose of general comparison when making tests.

For a given boiler pressure and temperature, an evaporative factor can be obtained from the table on next page, which, multiplied by the lbs. of water evaporated per lb. of fuel, will give the equivalent evaporation from and at 212° Fah.

Example.—If a boiler evaporates 8 lbs. of water per lb. of coal, with a feed at 80° Fah., and a steam pressure of 120 lbs., by gauge find the equivalent evaporation from and at 212° Fah.

From the table of evaporation factors we see that for a boiler pressure of 120 lbs. and a feed at 80° Fah., the factor is 1·181. Then $1{\cdot}181 \times 8 = 9{\cdot}4$, which is the equivalent number of lbs. of water evaporated per lb. of fuel from and at 212° Fah.

Another method of obtaining the evaporation from and at 212° Fah. is by means of the steam tables on page 18. From this we see that 1 lb. of steam at $105 + 15 = 120$ lbs. absolute is, with a feed at 32° Fah., equal to 1185·9 units, with a feed at 80° Fah. it would be $80 - 32 = 48$ units less, or $1185{\cdot}9 - 48 = 1137{\cdot}9$. Therefore the heat expended in evaporating 8 lbs. of water would be $1137{\cdot}9 \times 8 = 9103{\cdot}2$ units. To convert 1 lb. of water at 212° Fah. into steam at the same temperature, 966 units are required. Therefore the equivalent evaporation is $9103{\cdot}2 \div 966 = 9{\cdot}4$ lbs.

Heat Effect on Water.

The application of heat to water sets up convection currents, and when applied to the lowest part of a vessel containing water, they consist of ascending and descending currents.

The heated water becomes lighter, volume for volume, and so ascends, and the colder water descends and takes its place; thus a continuous circulation is going on due to the heated particles of water rising and the colder water descending.

The proper application of heat to water in a boiler is very important, and to obtain the best results it is necessary that the greater amount of heat should be applied to the lowest possible part of the heating surface.

Good circulation is of utmost importance, and it is equally necessary that sufficient water and steam space is provided, so that plenty of freedom is given for the escape of the steam bubbles and for the

FACTORS OF EVAPORATION.

Temp. of Feed Water Deg. F.	Steam Pressure by Gauge.												
	50	60	70	80	90	100	110	120	130	140	150	160	170
32	1.214	1.216	1.220	1.222	1.225	1.227	1.229	1.231	1.232	1.234	1.236	1.237	1.239
40	1.206	1.209	1.212	1.214	1.216	1.219	1.220	1.222	1.224	1.226	1.227	1.229	1.230
50	1.195	1.197	1.201	1.204	1.206	1.208	1.210	1.212	1.214	1.215	1.217	1.218	1.220
60	1.185	1.188	1.191	1.193	1.196	1.198	1.200	1.202	1.203	1.205	1.207	1·208	1.210
70	1.175	1.178	1.180	1.183	1.185	1.187	1.189	1.191	1.193	1.194	1.196	1.197	1.199
80	1.164	1.167	1.170	1.173	1.175	1.177	1.179	1.181	1.183	1.184	1.186	1.187	1.189
90	1.154	1.157	1.160	1.162	1.165	1.167	1.169	1.170	1.172	1.174	1.176	1.177	1.179
100	1.144	1.147	1.150	1.152	1.154	1.156	1.158	1.160	1.162	1.164	1.165	1.167	1.168
110	1.133	1.136	1.139	1.142	1.144	1.146	1.148	1.150	1.152	1.153	1.155	1.156	1.158
120	1.123	1.126	1.129	1.131	1.133	1.136	1.138	1.140	1.141	1.143	1.145	1.146	1.147
130	1.113	1.116	1.118	1.121	1.123	1.125	1.127	1.129	1.130	1.132	1.134	1.136	1.137
140	1.102	1.105	1.108	1.110	1.113	1.115	1.117	1.119	1.120	1.122	1.124	1.125	1.127
150	1.091	1.095	1.098	1.100	1.102	1.104	1.106	1.108	1.110	1.111	1.113	1.115	1.116
160	1.081	1.084	1.087	1.090	1.092	1.094	1.096	1.098	1.100	1.101	1.103	1.104	1.106
170	1.070	1.074	1.077	1.079	1.081	1.083	1.085	1.087	1.089	1.091	1.092	1.094	1.095
180	1.060	1.063	1.066	1.069	1.071	1.073	1.075	1.077	1.079	1.080	1.082	1.083	1.085
190	1.050	1.053	1.056	1.058	1.060	1.063	1.065	1.066	1.068	1.070	1.071	1.073	1.074
200	1.039	1.043	1.045	1.048	1.050	1.052	1.054	1.056	1.058	1.059	1.061	1.063	1.064
210	1.029	1.032	1.035	1.037	1.040	1.042	1.044	1.046	1.047	1.049	1.051	1.052	1.053

Temp. of Feed Water Deg. F.	Steam Pressure by Gauge.												
	180	190	200	210	220	230	240	250	260	270	280	290	300
32	1.240	1.241	1.243	1.244	1.245	1.246	1.247	1.248	1.250	1.251	1.252	1.253	1.254
40	1.232	1.233	1.234	1.236	1.237	1.238	1.239	1.240	1.241	1.242	1.243	1.244	1.245
50	1.221	1.223	1.224	1.225	1.226	1.228	1.229	1.230	1.231	1.232	1.233	1.234	1.235
60	1.211	1.212	1.214	1.215	1.216	1.217	1.218	1.219	1.220	1.221	1.222	1.223	1.224
70	1.200	1.202	1.203	1.205	1.206	1.207	1.208	1.209	1.210	1.211	1.212	1.213	1.214
80	1.190	1.192	1.193	1.194	1.195	1.196	1.198	1.199	1.200	1.201	1.202	1.203	1.204
90	1.180	1.181	1.183	1.184	1.185	1.186	1.187	1.188	1.189	1.190	1.191	1.192	1.193
100	1.170	1.171	1.172	1.174	1.175	1.176	1.177	1.178	1.179	1.180	1.181	1.182	1.183
110	1.159	1.160	1.162	1.163	1.164	1.166	1.167	1.168	1.169	1.170	1.171	1.172	1.173
120	1.149	1.150	1.151	1.153	1.154	1.155	1.156	1.157	1.158	1.159	1.160	1.161	1.162
130	1.138	1.140	1.141	1.142	1.144	1.145	1.146	1.147	1.148	1.149	1.150	1.151	1.152
140	1.128	1.129	1.131	1.132	1.133	1.134	1.135	1.136	1.137	1.138	1.139	1.140	1.141
150	1.118	1.119	1.120	1.121	1.123	1.124	1.125	1.126	1.127	1.128	1.129	1.130	1.131
160	1.107	1.108	1.110	1.111	1.112	1.113	1.115	1.116	1.117	1.118	1.119	1.120	1.121
170	1.097	1.098	1.099	1.101	1.102	1.103	1.104	1.105	1.106	1.107	1.108	1.109	1.110
180	1.086	1.088	1.089	1.090	1.091	1.093	1.094	1.095	1.096	1.097	1.098	1.099	1.100
190	1.076	1.077	1.078	1.080	1.081	1.082	1.083	1.084	1.085	1.086	1.087	1.088	1.089
200	1.065	1.067	1.068	1.069	1.071	1.072	1.073	1.074	1.075	1.076	1.077	1.078	1.079
210	1.055	1.056	1.057	1.059	1.060	1.061	1.062	1.063	1.064	1.065	1.066	1.067	1.068

hot water of the ascending current. Unless sufficient steam and water space is allowed for, there will be no regularity of action and the steam pressure may be very erratic, rising and falling suddenly, and the water level may be subject to frequent and rapid changes in height.

If the steam space is restricted, the steam in passing from the water may carry some of the water with it and cause *priming.*

When steam attempts to escape through a restricted opening or tube, it has the tendency to cling to the sides and prevent the cold water from coming into proper contact with the tube or plate surface. The same occurs when heat is applied to one side of a vertical tube boiler; the steam formed at the lower end, in ascending, clings to the sides of the heated tube and prevents the water from coming into proper contact with the tube surface.

Circulation.

The unequal expansion, due to the difference of temperature to which high pressure marine boilers are subjected while raising steam, is generally admitted to be the cause of the leakage at the landings and rivets in the bottom of the boiler shell, and about the furnace landings below the fire bars. By comparing the difference of temperature between the top and bottom, and bearing in mind that the portion of the boiler shell heated and expanded is five times greater than the cold portion on the bottom, the reason that the bottoms get strained and leaky is easily understood. The expansion of iron due to a temperature 250° Fah. on an 18 foot plate is $\frac{3}{8}$ of an inch. Four-fifths of the boiler shell must therefore be lengthened $\frac{3}{8}$ of an inch, while the bottom is scarcely lengthened at all, and consequently the strain on the boiler must be beyond the elastic limit of iron. Hence it follows that the landings must either yield to the strain, or, as occasionally happens, the plates crack between the rivet holes, or even the solid plates give way. The only remedy for the above is some method of heating and circulating the water in the boiler while raising steam, and thus preventing unequal expansion.

Hydrokineter.—A device for increasing the circulation, and one that is very much in use with marine type boilers, is the hydrokineter, manufactured by Messrs. Weir, Ltd., of Glasgow. A section of a three-nozzle hydrokineter is shown in Fig. 12. The flange of the first or steam nozzle is fixed on the inside of the boiler shell, and set in the direction that the circulating current is to take. On this nozzle are fixed two outer or induction nozzles, and the back end of one and the outer ring of the other are perforated to admit water

between. Steam from the donkey boiler is admitted by the check and stop valve to the steam nozzle, and, becoming condensed, throws a jet of water through the second nozzle. The volume of water is increased in passing through the outer nozzle. It then enters the bottom of the boiler and induces a current.

The purpose of the two outer nozzles is more effectually to direct the force of the jet in the direction in which circulation is desired. When a steam jet is blown in openly, as the water gets heated to a certain temperature, the steam, on leaving the nozzle, expands and

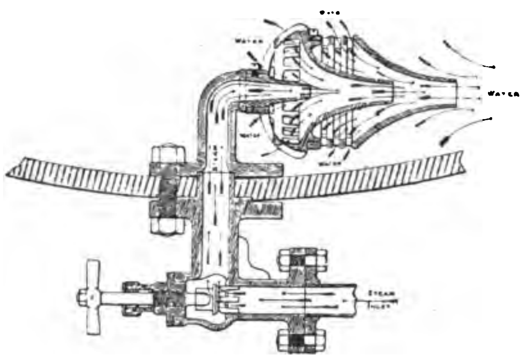


FIG. 12.—Weir's hydrokineter.

impairs the force of the jet. With the three-nozzle arrangement this is obviated. The water being directed on the steam jet, the steam is condensed between the first and second nozzles until the temperature of the water reaches about 270° Fah. The outer nozzles then come into play as a condenser, keeping the steam from expanding, and directing the jet straight into the water in the bottom of the boiler, until the pressure reaches that of the steam jet. The check valve now closes to prevent the water from being forced back into the donkey boiler.

Fitting Up and Using the Hydrokineter.

In single-ended boilers, the hydrokineter is placed on the centre, at equal distances from the ends. With double-ended boilers, two hydrokineters are used, and these are placed one-fourth the length of the boiler from each end. In two-furnace boilers, the hydrokineter should be placed between the furnaces. The steam should be admitted to the hydrokineter when the fires are lighted, but when the water approaches the boiling-point the dampers should be closed, as the fires by that time are strong, and the temperature would rise

very rapidly if it were not checked to some extent. When steam shows in the boiler, care should be taken to allow at least 30 minutes for the steam to rise till it reaches the pressure in the donkey boiler, so that the water in the bottom may be thoroughly mixed, and heated up to the temperature due to the pressure. Care must be taken to allow sufficient time for the steam to rise till it reaches 30 lbs. pressure, and the hydrokineter will easily bring up the temperature of the water in the bottom to 270° Fah., using steam from the donkey boiler at 30 lbs. pressure.

Where a large number of boilers are in use, steam should first be raised in one of the boilers, the water being circulated by steam from the donkey boiler. The fires of the remaining boilers should then be lighted, and steam from the first main boiler used to circulate the water in the others. In this case the steam jets can be increased, so that the steam may be raised as rapidly as possible.

Heating Surface.

The heating surface of a boiler is the area of that portion of the boiler surface which is in contact with water on one side and hot gases on the other. The area is usually measured on the fire-side of the plates or tubes.

The efficiency and power of the boiler depend not only on the amount of heating surface, but also on the general arrangement and design of the heating surface. To obtain a good evaporation, the heating surface should be arranged so that the heat generated by the combustion of the fuel will be absorbed as much as possible without interfering with the draught.

Heat of Combustion.

Fuel consumed in a furnace gives off heat, the amount of which can be found approximately by obtaining the calorific value of the fuel. The heat obtained from combustion is usually regarded as being in two forms, radiant and convected.

Radiant heat gives up its heat within the limits of its range, and raises the temperature of neighbouring objects of lower temperature than itself; its effect diminishes quickly as the distance from the source of heat increases.

Convected heat has a much larger range of application, because its heating effect is carried by particles of air and gas, and by conduction transfer its heat to surfaces considerably removed from its source.

The temperature of combustion is of considerable importance in

steam generation, because heat transmission varies as the square of the difference of the temperature on either side of a boiler plate.

The appearance of the fire is some indication of its temperature, and this can be seen with the aid of coloured glasses. The following colours correspond approximately with degrees Fahrenheit.

Dazzling white .	2700° Fah.	Clear cherry-red .	1800° Fah.
White . . .	2500° ,,	Cherry-red . .	1470° ,,
Orange . .	2000° ,,	Dull red . .	1290° ,,

Heat Transmission.

The transmission of heat from the combustion of fuel to the boiler heating surface, and from thence to the water, is a subject upon which many authorities disagree. No formula will give accurately the rate of heat transmission under the varying conditions which prevail when generating steam in a boiler.

When fuel is consumed in a boiler furnace, the heat of combustion is transmitted to the heating surfaces, and from thence to the water, by radiation, convection, and conduction. The radiant heat absorbed may vary from 30 to 50 per cent. of the whole, but the relative amounts of heat derived from convection and conduction depend on so many different factors that a general statement is of very little use.

The difficulty encountered in dealing with heat transmission in practice is to find the actual temperature on either side of the boiler heating surface. Two authorities give the temperature of the fire-side of the heating surface as being only 36° Fah. and 68° Fah. respectively higher than on the water-side, and it is generally accepted that the temperature difference is approximately within this range.

It has been found that heat passes much more rapidly between the boiler heating surface and the water than between the hot gases and the plates.

In transmission of heat by conduction and convection, two important factors have to be contended with. These are—

A gas film on the fire-side of the heating surface.

A water film on the water-side of the heating surface.

Thus in the convection and conduction of heat from the fire to the water, the heat particles will first encounter the gas film, then possibly a layer of soot, then the boiler plate, afterwards a possible layer of scale, then through the water film, and from the water film to the water.

The experiments of Professor Dalby[1] go to prove that neither

[1] "Heat Transmission," Inst. Mech. Engineer, Oct., 1909.

the thickness of the plate nor the material from which it is made, has much effect on the transmission of heat.

The transmission of heat through a metal plate can be found approximately by the following formula, the temperature on either side of the plate being constant and of large area :—

Let N = number of units traversing per second a unit section of one sq. foot.

θ = difference in temperatures on either side of the plate.

x = thickness of metal in inches.

C = conductivity of metal (in same unit as N).

$$\text{Then } N = C \times \frac{\theta}{x}.$$

This formula, applied to boiler practice, is of very little use owing to the difficulty of determining the temperatures on either side of the plate; if the temperature of the hot gases on one side, and the water on the other are taken, the rate of heat transmission would be considerably greater than that known to exist, and therefore it is obvious that the difference of temperatures on the two sides of the plate, are very much lower than the difference in the temperatures of the water and the hot gases.

The following empirical formula by Rankine, based on experiments, gives results approximate to working conditions, for heat transmitted per sq. foot per hour.

Let t_1 = temperature of hot gases.

t_2 = temperature of water.

e = 160 to 200.

Q = quantity of heat per sq. foot per hour.

$$Q = \frac{(t_1 - t_2)^2}{e} = \text{B.T.U.}$$

Boiler Horse-Power.

The horse-power of a boiler has been, and in many cases is still, based upon the horse-power developed by the engine which it supplies with steam.

The nominal horse-power of a boiler is, even at the present time, calculated according to the amount of heating surface, 10 to 12 sq. feet being allowed per horse-power. This method of classification is of very little use, because the various types of engines require different amounts of steam per horse-power indicated, according to their design and efficiency.

Another method of indicating the nominal horse-power of a boiler

was based on the evaporation of 1 cub. foot or 62·45 lbs. of water. This method also is of very little value.

The amount of steam required by an engine to develop 1 horse-power may vary between 11 lbs. and 40 lbs. or even more, while feed pumps and certain other auxiliaries often require as much as 200 lbs. of steam per horse-power.

The following figures give the approximate steam consumption of various types of engines per indicated horse-power per hour :—

High class triple and quadruple engines under favourable conditions	11 to 13 lbs.
Triple and quadruple engines under ordinary conditions	12 ,, 15 ,,
Triple and quadruple engines under variable loads	15 ,, 20 ,,
Compound engines under variable loads	18 ,, 25 ,,
Simple condensing engines	25 ,, 35 ,,
Simple non-condensing engines	30 ,, 40 ,,
Simple non-condensing engines of inferior make and small size	40 upwards.

To allow for economical working, and to give an ample supply of steam, at least 50 per cent. more than the above figures should be allowed.

The power of a boiler should be in terms of horse-power, because the energy is actually generated in the boiler, the engine taking its power from the boiler, using some and wasting most. It is obviously unfair to hold the boiler responsible for the shortcomings of the engine, as it is the function of the boiler to generate power and not to develop it.

The following example will show the futility of indicating the horse-power of a boiler, according to the power developed in the engine :—

Example.—

Grate area of boiler	45 sq. ft.
Coal consumption	24 lbs. per sq. ft.
Water evaporated per lb. of fuel	8·5 lbs.

Then water evaporated per hour $45 \times 24 \times 8{\cdot}5 = 9180$ lbs.

If a simple type of non-condensing engine, using 30 lbs. of steam per horse-power hour, is being supplied, the horse-power would be $9180 \div 30 = 306$, whereas, if a modern quadruple condensing engine, using only 12 lbs. of steam per horse-power hour, is being used, then the horse-power would be $9180 \div 12 = 765$ or $2\frac{1}{2}$ times greater.

The most useful method of indicating the power of a boiler, and one which steam users should insist upon, is the evaporation at a given pressure of an equivalent of a definite number of lbs. of water from and at 212° Fah., when burning a certain amount of fuel per sq. foot of fire-grate under normal condition of draught. The

only question of doubt would be the calorific value of the fuel, but if this were also given, the equivalent evaporation for fuel of a different calorific value could be found approximately by calculation.

The evaporation of water by any boiler can be found within practical limits by means of tests, and if the steam consumption of the engine to be supplied with steam is known, then the horse-power of the boiler can be calculated.

Selecting a Boiler.

In deciding upon a particular design of boiler, the following information should be obtained and carefully considered.

1. The approximate number of pounds of water to be evaporated per hour.
2. The class of fuel to be used.
3. The possibility of variation in load.
4. Steam pressure.
5. Durability and simplicity of design.
6. The available floor space.
7. Transport difficulties.
8. Efficiency and economy with regard to the initial cost.

Boiler Efficiency.

The evaporative efficiency of a boiler is the percentage ratio between the heat developed in the boiler and the heat absorbed by the water. This can be expressed as—

$$\text{Efficiency} = \frac{\text{heat absorbed by water per lb. of fuel}}{\text{heat developed per lb. of fuel}}.$$

The efficiency can also be taken as the ratio of the amount of heat contained in the fuel, to the heat transmitted to the water; or the amount of water evaporated from and at 212° Fah., divided by the amount of water which the fuel would evaporate if all its heat were transmitted to the water.

To find the efficiency let—

W = water evaporated per lb. of fuel.
C = calorific value of fuel.
H = total heat of 1 lb. of steam from feed to temperature.

$$\text{Then percentage efficiency of boiler} = \frac{W \times H}{C} \times 100.$$

CHAPTER III.

FUEL AND ITS COMBUSTION.

Any combustible substance which is used for the production of artificial heat can be regarded as fuel, and under that heading may be included such substances as alcohol, wax, tallow, dried grass, and other inflammable bodies which are used more or less to produce heat.

In England, coal, owing to its abundance and cheapness, is the common fuel; on the Continent, wood and peat are more generally used, but, whatever the substances used, the heat evolved is chiefly derived from the carbon and hydrogen contained in them.

The term fuel generally indicates the more common sources of heat, such as coal, petroleum, wood, and peat.

Coal.

Coal is a solid mineralised vegetable matter, which has been formed by the decomposition of vegetable and woody matter that at one time grew and afterwards decayed on the earth's surface. Several theories have been advanced as to the origin of coal. The one generally accepted is that the luxuriant vegetation which prevailed during the carboniferous period, grew and decayed upon land only slightly raised above the sea level, and that by slow subsidence this thick layer of vegetable matter gradually sank below the water level, and became covered with mud, sand, and other mineral sediment; then, by the upheaval of the sea bottom, a land surface was once more formed and became covered with a dense mass of plants, which in course of time decayed and sank as before. At length, when thick layers of stratified matter became accumulated, a great pressure was produced, and this, acting with chemical changes, gradually mineralised the layers of vegetable matter into coal.

Classification of Coal.

For most practical purposes coal is classified as either anthracite or bituminous, but each of these qualities can be sub-divided into coals of varying degrees of quality.

Anthracite is said to be the coal of oldest formation, and to have been the result of application of the greatest pressure and heat. It is chiefly found in the United States of America, but considerable quantities are to be found in the South Wales coal-fields. It is hard, dense, and brittle, very little volatile, is difficult to ignite, and gives practically no smoke and very little flame.

Semi-anthracite is mined in enormous quantities from the coal-fields of South Wales, and also in Belgium. It gives a local heat, is of a hard, dusty nature, and nearly smokeless.

Semi-bituminous, or hard bituminous coal, is found in large quantities in the Midlands, and is used to a great extent in the manufacture of gas.

Bituminous coal is to be found in all parts of the world, and during combustion it will be found to cake, soften, and swell into a pasty mass, and when distilled will yield a large percentage of coke.

Lignite is the name given to the coal of latest formation, and it is not found to any great extent in the United Kingdom. Lignite often possesses a woody structure, and is black or brown in colour, the structure frequently being found very similar to that of pitch.

Composition of Various Coals.

The elements in coal from which heat is derived by combustion are: carbon, hydrogen, and sulphur. For most practical purposes, carbon and hydrogen are the only elements which need be seriously taken into consideration in calculating the calorific value of coal.

The following analyses show the composition of various grades of coal:—

TABLE 1.—COMPOSITION PER CENT. AND HEAT OF COMBUSTION OF FUELS.

	Carbon.	Hydrogen.	Sulphur.	Heat of Combustion.	Pounds of Water Evaporated from and at 212° approximately.
Wood	48	5·0	—	7700	8·0
Peat	53	5·6	—	9660	10·0
Cannel coal	78	5·0	·4	15080	15·6
Bituminous coal	85	5·5	·78	15800	16·0
Anthracite	91	3·5	·6	14700	15·2

The following table, compiled by Dr. Percy, shows the gradual conversion of woody fibre into peat, coal, and graphite, the carbon being kept as a constant.

TABLE 1A.

	Carbon.	Hydrogen.	Oxygen.
Wood	100	12·18	88·07
Peat	100	9·85	55·67
Lignite	100	8·37	42·42
Bituminous coal	100	6·12	21·23
Anthracite	100	4·75	5·28
Graphite	100	0·00	0·00

Combustion of Coal.

The most valuable combustible elements in coal are hydrogen and carbon, and in order that the potential energy which they possess may be converted into heat, sufficient oxygen must be brought into chemical contact with them, at a temperature high enough to bring about combustion. It is the combination of two elements, under conditions suitable for forming a new compound, that raises the temperature of the compound, and thereby produces a luminous heated mass. Whatever the substances used for producing heat, this chemical change must take place, and the elements must be allowed to combine under favourable conditions.

Calorific Value of Fuel.—The theoretical heating value, or calorific value, of a fuel is usually expressed in British Thermal Units, this being the standard mostly accepted in the United Kingdom and in the United States of America. It is written as B.T.U., and represents the amount of heat required to raise 1 lb. of pure water at 39·1° Fah. through 1° of temperature.

As it is possible actually to measure the amount of heat obtainable from the combustion of a known quantity of hydrogen, carbon, or sulphur, burnt under perfect conditions, it is also possible to calculate the theoretical heating value from a chemical analysis of any fuel, if due allowance is made for moisture.

Calorific Value.—The accepted calorific values of carbon, hydrogen, and sulphur, burnt under perfect conditions, are—

1 lb. carbon = 14,544 British Thermal Units.
1 lb. hydrogen = 62,032 „ „ „
1 lb. sulphur = 4,032 „ „ „

For most practical purposes these figures can be taken as carbon, 14,500 B.T.U., hydrogen, 62,000 B.T.U., sulphur, 4,000 B.T.U.

Calculated Calorific Value.—To calculate the approximate calorific value of a fuel containing a known percentage of carbon, hydrogen, oxygen, and sulphur, the following formula can be used:—

$$145(C + 4{\cdot}28\,(H - \tfrac{O}{8}) + {\cdot}28S) = \text{B.T.U. per lb.}$$

Taking the following percentage analysis of a good sample of South Wales anthracite: Carbon, 91·67; hydrogen, 3·93; oxygen, 1·87; nitrogen, 0·44; sulphur, 0·77; ash, 1·32.

The above formula would give—

$145(91{\cdot}67 + 4{\cdot}28\,(3{\cdot}93 - \frac{1{\cdot}87}{8}) + {\cdot}28 \times {\cdot}77) = 15{,}620$ B.T.U. per lb.

Calorific Values of Various Coals.—The value in British Thermal Units of various classes of coals is approximately as follows:—

Powell Duffryn, 15,500; Nixon's Navigation, 15,050; Newcastle, 14,800; Derbyshire, 13,860; Yorkshire, 13,800; Scotch, 13,500.

Combustion of Carbon.

In order that carbon can be burnt to the best advantage, sufficient oxygen must be added to allow of perfect combustion.

Carbon burnt to form carbon dioxide, (CO_2), gives 14,500 B.T.U. per lb.

Carbon burnt to form carbon monoxide, (CO), gives only 4,400 B.T.U. per lb.

It will be seen that incomplete combustion results in a great loss of heat, and, therefore, every endeavour should be made to bring about the correct chemical change.

To obtain 1 molecule of carbon dioxide, 2 atoms of oxygen must combine with 1 atom of carbon, and as the atomic weight of carbon is 12, and the atomic weight of oxygen 16, the relative weights are as 12 is to 32. Thus, 8 lbs. of oxygen combining with 3 lbs. of carbon will form 11 lbs. of carbon dioxide.

Amount of Air for Combustion.—If 3 lbs. of carbon require 8 lbs. of oxygen to convert it into carbon dioxide, then 1 lb. will require 2·66 lbs. of oxygen. Air contains 21 per cent. of oxygen by volume, and 23 per cent. by weight.

23 per cent. of oxygen + 77 per cent. of nitrogen = 100 per cent. air.

Therefore, to obtain 1 lb. of oxygen we must use 100 ÷ 23 lbs. of air = 4·35 lbs.; and because 1 lb. of carbon requires 2·66 lbs. of oxygen, we must use 2·66 × 4·35 = 11·6 lbs. of air.

Then to find the amount of air required to burn 1 lb. of carbon to CO_2, if C be the percentage of carbon in the fuel, and the weight of air A,

$$A = \frac{C \times 2{\cdot}67}{100} \times \frac{100}{23} = \frac{C \times 2{\cdot}67}{23} = C \times {\cdot}116 \text{ lbs.}$$

And if the fuel contains 80 per cent. of carbon, the amount of air

to convert the carbon into CO_2 would be $80 \times \cdot 116 = 9 \cdot 28$ lbs. That is, 9·28 lbs. of air would be required for each lb. of fuel, *for the carbon alone.*

Combustion of Hydrogen.

One lb. of hydrogen combining with the correct amount of oxygen to form H_2O gives out about 62,000 B.T.U. To obtain 2 molecules of H_2O, 2 atoms of hydrogen must combine with 1 atom of oxygen, and as the atomic weight of hydrogen is 1, and the atomic weight of oxygen 16, the relative weights are as 2 is to 16. Thus 1 lb. of hydrogen combining with 8 lbs. of oxygen will yield 9 lbs. of H_2O.

Amount of Air for Combustion.—If 1 lb. of hydrogen requires 8 lbs. of oxygen to convert it into H_2O, then to find the amount of air required to burn 1 lb. of hydrogen to H_2O, if H be the percentage of hydrogen in the fuel, and the weight of air A,

$$A = \frac{H \times 8}{100} \times \frac{100}{23} = \frac{H \times 8}{23} = H \times \cdot 348 \text{ lb.}$$

And if the fuel contained 3·93 of hydrogen, the amount of air to convert the hydrogen to H_2O would be: $3 \cdot 93 \times \cdot 348 = 1 \cdot 36$. That is, 1·36 lbs. of air would be required for each lb. of fuel for *hydrogen alone.*

During the process of combustion the hydrogen will produce nine times its weight in steam or water vapour; thus, 1 lb. of hydrogen will yield 9 lbs. of steam, the latent heat of which will be carried away with the waste gases. The latent heat of steam at atmospheric pressure being 966, since $966 \times 9 = 8694$, the number of British Thermal Units thus carried away is 8694; hence $62000 - 8694 = 53306$ gives the lower or effective calorific value of hydrogen.

Combustion of Hydrogen and Carbon.

The weight of air for the combustion of hydrogen and carbon can be obtained from the following formula, in which A = air in lbs., H = percentage of hydrogen, C = percentage of carbon:—

$$A = C \times \cdot 116 + H \times \cdot 348 \text{ lb.}$$

If the fuel contains 80 per cent. of carbon and 3·93 per cent. of hydrogen, the weight of air required for each lb. of fuel to complete the combustion of the carbon and hydrogen would be—

$$80 \times \cdot 116 + 3 \cdot 93 \times \cdot 348 = 10 \cdot 6 \text{ lbs.}$$

Combustion of Sulphur.

Sulphur combining with oxygen to form sulphur dioxide SO_2, will yield about 4000 B.T.U. per lb. One atom of sulphur com-

bining with 2 atoms of oxygen gives 1 molecule of sulphur dioxide, and the atomic weight of sulphur is 32.

Thus, if 1 lb. of sulphur combines with 1 lb. of oxygen, it yields 2 lbs. of sulphur dioxide, which gives about 4000 B.T.U.

The weight of air required to burn 1 lb. of sulphur to SO_2 if S be the percentage of sulphur, and the weight of air A—

$$A = S \times \frac{100}{23} = S \times 4{\cdot}34 \text{ lbs.}$$

Combustion of Hydrogen + Carbon + Sulphur.—The weight of air for the combustion of H + C + S can be obtained from the following: A = percentage of air, H = percentage of hydrogen, C = percentage of carbon, S = sulphur:—

$$A = H \times {\cdot}348 + C \times {\cdot}116 + S \times 4{\cdot}34.$$

Example:—

If the fuel contained 80 per cent. of carbon, 3·93 per cent. of hydrogen, and 0·77 per cent. of sulphur, the weight of air required for each lb. of fuel would be—

$$80 \times {\cdot}116 + 3{\cdot}93 \times {\cdot}348 + 0{\cdot}77 \times 4{\cdot}34 = 13{\cdot}9 \text{ lbs.}$$

Volume of Air for Combustion.—One cub. foot of air under normal conditions of temperature weighs 566·3 grains, or ·0809 of 1 lb. Then to find the volume of air, divide weight in lbs. by ·0809. For fuel containing the above percentages of hydrogen, carbon, and sulphur, then—

$$\frac{80 \times {\cdot}116 + 3{\cdot}93 \times {\cdot}348 + 0{\cdot}77 \times 4{\cdot}34}{{\cdot}0809} = 173{\cdot}7 \text{ cub. ft. of air per lb. of fuel.}$$

This represents the theoretical quantity of air only; in actual practice with natural draught, 24 *lbs. of air should be supplied for each lb. of coal burnt*; with forced draught *about* 18 *lbs. would be enough.* In volume this would be approximately 300 and 200 cub. feet respectively.

Flue Gases.

An analysis of flue gases forms an effective check on the completeness of combustion taking place in the furnace. If complete combustion were possible with the quantity of air as calculated above, the flue gases would consist of 21 per cent. carbon dioxide and 79 per cent. nitrogen. The reason for this is that whatever volume of oxygen is used in the combustion of carbon, the same volume of carbon dioxide is formed. However, complete combustion is not possible under these circumstances, as some of the carbon is burnt to carbon monoxide. Now 1 lb. of carbon burning to carbon dioxide

yields 14,500 B.T.U., and 1 lb. of carbon burning to carbon monoxide yields 4,400 B.T.U. Hence the presence of carbon monoxide in the flue gases indicates that some of the carbon is yielding only about 30 per cent. of its proper heat value. Excess air over the calculated quantity is then essential, and so the flue gases must contain unused oxygen, and this reduces the percentage of carbon dioxide so that the percentages of carbon dioxide and oxygen together make 21. It is found in practice that the best results are obtained when the percentage of carbon dioxide is from 12 to 14, that is when about one and a half times the calculated volume of air is used, or when the volume of air admitted is about 225 cub. feet per lb. of carbon.

Calorific Value of Solid Fuels.

No fuel calorimeters, however elaborate, give absolutely correct calorific values. In every case allowance has to be made for the delicacy of the thermometer being used. It is often of greater importance to know the comparative calorific values of fuels than the absolute figure. Thus, if a purchase of coal was being made, and a series of samples submitted to tests, the one to give the highest calorific value — other things being equal — would be the most economical. This would also be the case if it were desired to discover whether coal from a given source varied in quality from time to time.

Any instrument, therefore, which yields concordant results, with a close approximation to accuracy, is of equal value to the most expensive forms. For all ordinary purposes the Darling's Calorimeter, shown in Fig. 13 and used with the glass vessel, suffices. This form of calorimeter can be used for solid fuels generally and can be ignited electrically or by means of sulphur. If coal is being tested the sample is placed in the crucible C, and oxygen is supplied through tube O; this tube can be adjusted vertically in the rubber stopper at the top of the bell B. The latter rests upon a brass frame R, and is clamped to it by means of three screws. The frame contains a trunk A, through which the products of combustion pass to the distributor H.

Use of the Calorimeter.

1. Carefully grind up an average sample of the fuel in an iron mortar, and weigh out 1 to 1·5 grams in the crucible. Brush any particles from the sides into a mass at the bottom.

2. Prepare a quantity of water at a temperature about 2·5° C. below the temperature of the room. Water drawn from the tap

varies in temperature according to the season; and usually it will be necessary to add a little warm water to it in order to bring it to the requisite temperature. Measure out 1400 c.c. into the vessel.

3. Place the crucible in position, and fasten the glass cover down upon the rubber ring by means of the screws, so as to form an airtight joint. The screw must be turned until a resistance is felt; any further tightening of the screws might crack the glass cover.

4. Insert the rubber stopper into the neck, so that the platinum ignition wire is embedded in the fuel. The copper wire should terminate about level with the rim of the crucible, and the tube delivering the oxygen about $\frac{1}{2}$ inch above the surface of the fuel.

5. Turn on a gentle stream of oxygen from the gasholder, and

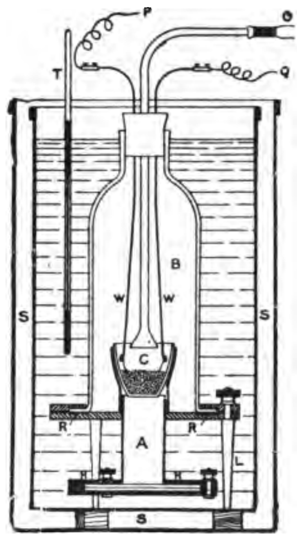


FIG. 13.—Darling's calorimeter.

immerse the apparatus in the water. Carefully note the temperature of the water, and complete the battery circuit. As soon as the fuel is ignited, disconnect the battery. Allow the combustion to proceed steadily until completed, then continue passing the oxygen, mixing the water by lifting the combustion arrangement up and down, until no further rise of temperature is observed. Note the temperature carefully.

Precautions.—1. The oxygen must never be admitted so rapidly as to cause the particles to be blown out of the crucible. The time required to burn 1 gram of average coal in a steady stream of oxygen is about 5 minutes. 2. If the sample is observed to burn with a smoky flame, the combustion must be stopped, as the result would

be valueless owing to unburnt carbon. A second combustion should be performed with the end of the oxygen tube 1 inch below the stopper until all volatile matter has burnt off, after which the tube may be pushed down to the crucible and the combustion completed. 3. During the combustion the tube delivering the oxygen should be moved about so as to ensure that every particle of coal is consumed. The flexibility of the rubber stopper allows of this operation being easily performed. In every case, near the end of combustion the supply of oxygen should be sufficient to cause the crucible to become visibly red-hot, whereby complete combustion is secured.

Calculation of the Calorific Value.

The calorific value is thus obtained :—

$$\frac{(\text{Weight of water} + \text{water equivalent}) \times \text{rise in temperature}}{\text{Weight of fuel taken}} = \text{calorific value.}$$

The figure expressing the "water equivalent" of the calorimeter is furnished with the apparatus, and is the weight of water which would absorb the same amount of heat as the apparatus.

Example :—

1 gram of coal burnt as above.

Water taken = 1400 c.cs. or grams.

Water equivalent of apparatus and vessel = 204 grams.

Temperature of water before combustion = 14° C.

Temperature of water after combustion = 19·20° C.

Temperature of room, 16·6° C.

$$\text{Calorific value} = \frac{(1400 + 204) \times (19{\cdot}20 - 14)}{1} = 8341 \text{ cals. per gram,}$$

or $8341 \times \frac{9}{5} = 15{,}014$ B.T.U. per lb.

The evaporative power[1] would be $8341 \div 537 = 15{\cdot}53$.

The Darling calorimeter can be ignited by means of sulphur instead of by the electric method. A small quantity of sulphur in powdered form is placed on top of the fuel. The oxygen is turned on gently, and the sulphur ignited by means of a red-hot rod.

Types of Calorimeters.

Many types of calorimeters are made, in most cases taking their name from the inventor. Thus we have the Darling, Rosenhain, Thompson, Junker, Roland Wild, Abady, Ure, Fischer, Parr, Hempel, Silbermann, Mahler Donkin, and a number of others. With any of these it is possible to obtain approximately the number of B.T.U. that a known quantity of fuel will yield.

[1] Lbs. of water at normal boiling-point, converted into steam at the same temperature, by burning 1 lb. of fuel.

The Ronald Wild calorimeter, illustrated in Fig. 14, is an apparatus, recently introduced, of the sodium peroxide type; that is to say, a mixture of the fuel and sodium peroxide is fired in a combustion chamber. With this type of calorimeter, which is cheap and simple, no oxygen cylinders or batteries are required, and it is possible to make a complete test of a solid fuel without any outside apparatus.

1. Place the stated amount of water in the water vessel, and the dried fuel to be tested, with proper amount of sodium peroxide, in

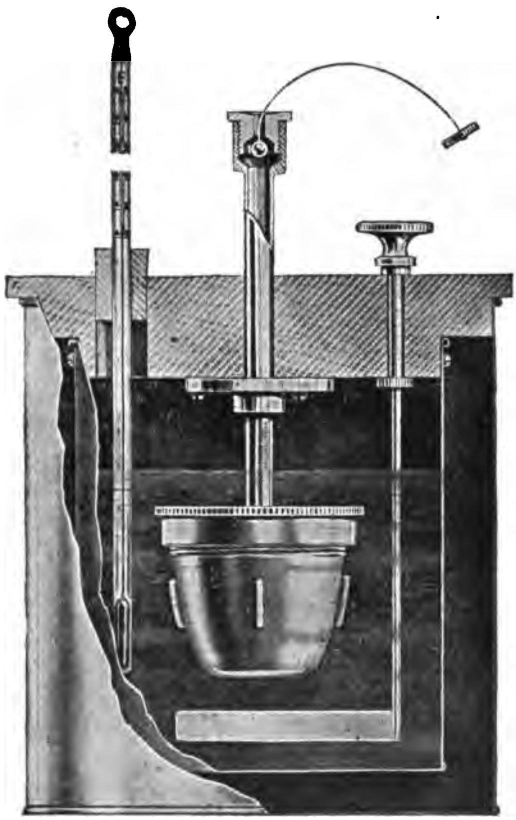


FIG. 14.—Ronald Wild calorimeter.

the crucible, and screw firmly home, so that no water gets into the crucible.

2. Stir water until temperature is constant and note same.

3. Heat to redness a small piece of nickel wire, drop same through valve opening D and draw valve home; agitate the water by means of the stirrer. Note highest temperature, which will be attained in 3 to 4 minutes.

4. The rise in temperature multiplied by 1000 = calorific value in B.T.U. of the sample.

5. The calorific value ÷ 967 = the evaporative power per lb. of the sample.

Example.—Water temperature 51°, rise 13·15. Calorific value 13,150 B.T.U. Evaporative power, per lb., 13·6.

Combustion of Liquid Fuels.

Great advances have been made in recent years in the more general use of petroleum and crude oils for firing boilers, and the increased production has extended its use wherever the cost is not excessive.

The term liquid fuel is applied to all hydrocarbon compounds which are sufficiently fluid to flow, or be pumped through pipes from one place to another. Natural mineral oil like petroleum contains many impurities, such as water and earthy matter, and is termed crude oil. During the process of refining, the crude oil is separated into: (1) petrol; (2) illuminating oils; (3) lubricating oils; and the residual is used as liquid fuel.

Coal gas tar, hydrocarbon oil from blast furnaces, and oil distilled from shale, are other examples of liquid fuels commonly used for firing boilers.

The advantages of oil fuel over the solid forms of fuel may be stated as :—

1. The superior evaporative power weight for weight.
2. Less space occupied in storing.
3. Ease of shipping and feeding fires.
4. Reduction of staff owing to above.
5. No bad effects and losses due to frequent opening of furnace doors.
6. Cleanliness and absence of dust and ashes.
7. Better conditions for obtaining proper combustion.

The disadvantages of oil fuels are :—

1. Cost and uncertainty of obtaining replenishments.
2. Danger of stowing large quantities.
3. Choking of sprayers due to impurities in the oil.
4. Smoke caused by incomplete combustion.

The composition of various oil fuels is shown in the following table:—

TABLE 2.—ANALYSIS OF OIL FUELS.

Name.	Carbon.	Hydrogen.	Sulphur and Oxygen.	Heat of Combustion, in B.T.U. per lb.
Borneo	87·8	10·78	1·32	18,830
Burmah	86·4	12·1	1·5	18,864
Caucasus	84·9	13·81	1·25	18,611
Texas	85·6	11·03	3·3	19,240
Beaumont	84·6	10·9	4·33	19,060

Flash-point.—The flash-point is the temperature at which the oil, if heated slowly in a cup, begins to give off a sufficient inflammable vapour to burn with a blue flash when a flame is brought into contact with it.

Combustion of Oil Fuel.

The amount of air required for the combustion of 1 lb. of oil fuel can be calculated if the composition of the fuel is known. With the practical combustion of coal or any form of hard fuel, an excess of air over the theoretical amount is always necessary to ensure complete combustion; so it is with oil fuel, but the excess is not so great. For every lb. of oil fuel burned it will be found necessary to supply from 13 to 14 lbs. of air.

The fact that a smaller amount of air is required for oil burning furnaces is due to the better conditions for combining and thoroughly mixing the fuel and the air. With the burning of coal, the air must force its way through the mass of fuel, and as it will take the line of least resistance, a great amount passes through hollow places, where the resistance is the least, and does not flow so freely through the thick masses of fuel where it is mostly required. In burning oil fuel, the oil is sprayed under pressure, and the air admitted in such a manner as to bring about a proper combination of air and fuel, resulting in more perfect combustion.

Air Supply.—The approximate weight of air per lb. of fuel can be calculated by the following formula, providing the percentage of carbon and hydrogen is known:—

$$A = \cdot 348\ H + \cdot 116\ C.$$

A = lbs. of air per lb. of oil fuel; H = percentage of hydrogen; C = percentage of carbon.

Example.—If a Texas oil contains 11 per cent. of hydrogen and 85 per cent. of carbon, how much air must be supplied?

$$A = 11 \times \cdot 348 + 85 \times \cdot 116 = 13 \cdot 6.$$

Or for every lb. of oil, 13·6 lbs. of air must be supplied.

Coke as a Boiler Fuel.

Coke is frequently used as a boiler fuel when a comparatively low evaporation is required. The following tests were carried out with a Cornish boiler and can be regarded as being correct under working conditions :—

Fuel Tested. System of Draught and Stoking.	Bituminous Coal. Natural Draught, Hand Fired.	Gas Coke. Special Blower and Hand Fired.	Gas Coke and Coke Breeze. Special Blower, Hand Fired.
Cost per ton delivered	25s. 0d.	25s. 0d.	10s. 0d. (breeze) 17s. 6d. (average)
Total grate area, sq. ft.	58	58	58
Amount of fuel used, lbs.	6,720	7,500	4,200 (coke) 4,200 (breeze)
Fuel burnt per sq. ft. grate area per hour	16·1	16·1	17·1
Total water evaporated, lbs.	45,950	65,800	59,200
Water evaporated per boiler per hour	3,530	4,520	3,860
Water evaporated per lb. of fuel	6·83	8·74	7·04
Water evaporated from and at 212° Fah. per lb. of fuel	7·74	9·8	7·99
Cost per 1000 gallons	14s. 5d.	11s. 8d.	9s. 5d.
Per cent. CO_2	not taken	16·0 per cent.	16·25 per cent.
Steam pressure	45 lbs.	58 lbs.	52 lbs.
Net working efficiency of plant, deducting 3 per cent. of steam used for special blower	72 per cent.	85 per cent.	80·9 per cent.
Financial saving effected by adopting coke fuel and forced draught	—	19 per cent.	34·6 per cent.

Oil-fuel Systems.—The installation shown in the sketch in Fig. 15 is known as the Thornycroft oil-fuel system. The method adopted is to spray the oil under pressure into the furnace by means of a special sprayer, the spray being produced within a cone of special construction, which introduces and mixes the air and the oil spray in such a manner as to produce perfect combustion. The system can be applied to either water-tube or marine type boilers. Water-tube boilers can be arranged for either oil only, or coal combined with oil.

The oil, which may be of any crude description, such as Texas,

Borneo, Mayout, or shale, is stored in tanks in any part of the ship, and drawn to the stokehold by a pump which forces it through the necessary strainers and the tubular steam heater to the sprayers.

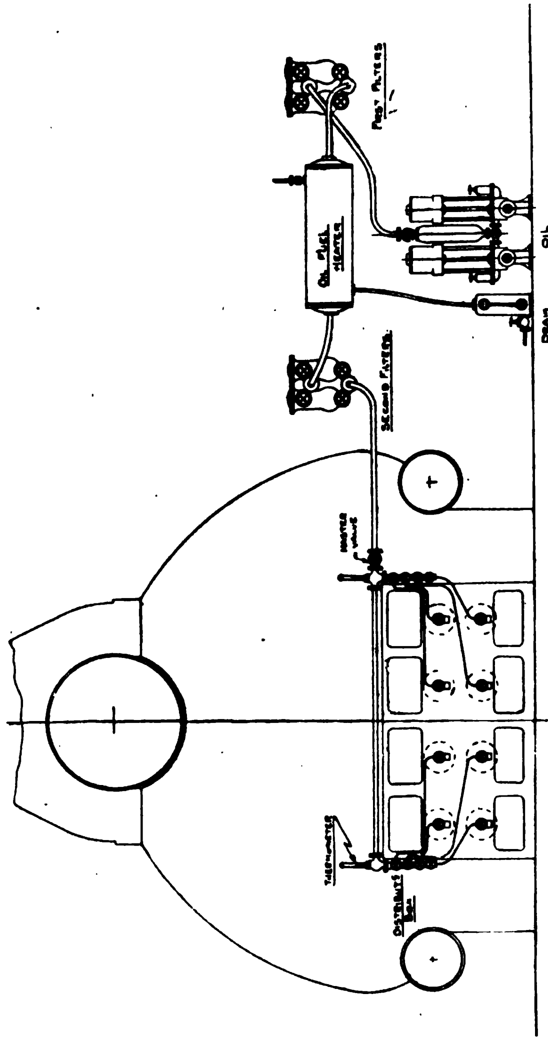


FIG. 15.—Arrangement of Thornycroft oil-fuel system.

Lighting up is effected with crude oil by means of a U tube and hand pump. Steam can be raised in from one-half to three-quarters of an hour.

When fitted in conjunction with Thornycroft boilers of the latest

design and fairly large size, the makers are prepared to guarantee that the equivalent evaporation will be at least 16½ lbs. of water from and at 212° Fah. per lb. of oil per hour, if the rate of evaporation does not exceed 4 to 5 lbs. per sq. foot from and at 212° Fah., and they will guarantee a maximum output of 16 lbs. per sq. foot with an evaporation of 14 lbs. per lb. of oil.

This rate of evaporation has no detrimental effect on the boiler if properly designed, while the combustion is smokeless up to moderate powers, and smoke is only just visible at the highest powers. These results enable very large powers to be developed on small weight, and the number of men necessary for a stokehold developing 16,000 horse-power is only three.

The Wallsend-Howden Liquid Fuel-burning System.—In this system the liquid fuel is injected into the furnaces under pressure by means of special oil-fuel pumps, these pumps being fitted in duplicate, so that one can act as a stand-by in case of breakdown in the working pump. On its way to the burners, the liquid fuel is passed through heaters and strainers in which it is heated to the correct temperature and then filtered.

The oil is forced into the furnace in the form of a conical spray of exceedingly fine particles, which burst into flame at a distance of 6 to 8 inches from the nozzle. The flame being conical, and there being no fire-bars fitted in the furnace, the whole circumference of the furnace is available for heating surface, as shown in Fig. 16. This is a great advantage in the ordinary multitubular boiler, as the lower portion of the boiler becomes heated sooner than would be the case with coal, and consequently the circulation of the water in the boiler is improved. Moreover, as the lower portion of the boiler is heated up uniformly with the upper portions, and there is no inrush of cold air, since there are no furnace doors to be opened, there is practically none of that straining action which results from unequal expansion and contraction, due to rapid changes consequent on the opening of the door in coal stoking.

In the construction of the furnace front arrangement, which constitutes the principal feature of the system, each of the oil fuel spraying nozzles projects through a baffle-plate, or the front plate of the casing, into an air trunk having lateral openings at its outer end. This air trunk projects concentrically with a second air trunk carried by the furnace front, and the annular space between the inner and outer air trunks is fitted with deflectors constructed in such a manner as to give the air passing through the annulus a spiral motion.

One result of this arrangement is that the openings for the supply of air are so disposed that direct radiation of heat from the furnace is prevented. The admission of air through the second or outer air trunk keeps the outer casing cool, and hence radiation from this part is reduced to a minimum.

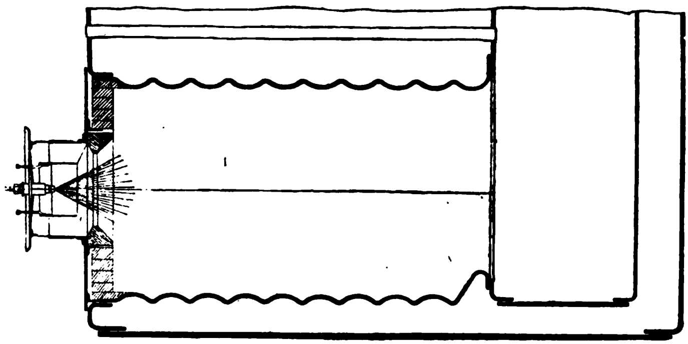


FIG. 16.—Oil-fired furnace of marine type boiler.

With this system there is no need for raising steam on one of the boilers by means of coal, as steam can be raised on any boiler from the start by means of oil fuel. This advantage is obtained by means of a special design of auxiliary heater and pump.

The following results were obtained on a ship indicating 9667

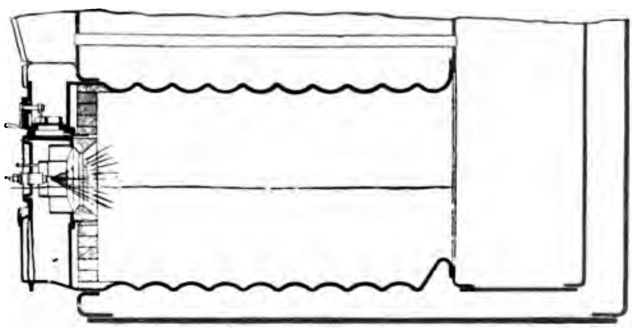


FIG. 17.—Oil-fired furnace Wallsend-Howden system.

horse-power, for a 47¾ hour run, fitted with the Howden system of forced draught and an oil-burning furnace, as seen in Fig. 17:—

Number of burners in use	27
Calorific value of oil used	19,620
Steam pressure, average lbs.	213
Pressure of air entering furnaces, inches	1¼
Temperature of air entering furnaces, Fah.	203°
Total weight of oil burned, lbs.	477,657

Weight of oil burned per hour, lbs.	10,003
Weight of oil burned per burner per hour, lbs.	370
Mean indicated h.p.	9667
Oil consumption per 1 h.p. per hour, all purposes, lbs.	1·034
Oil consumption per 1 h.p. for propelling machinery, lb.	0·907
Oil consumption per 1 h.p. main engines only, lb.	0·845

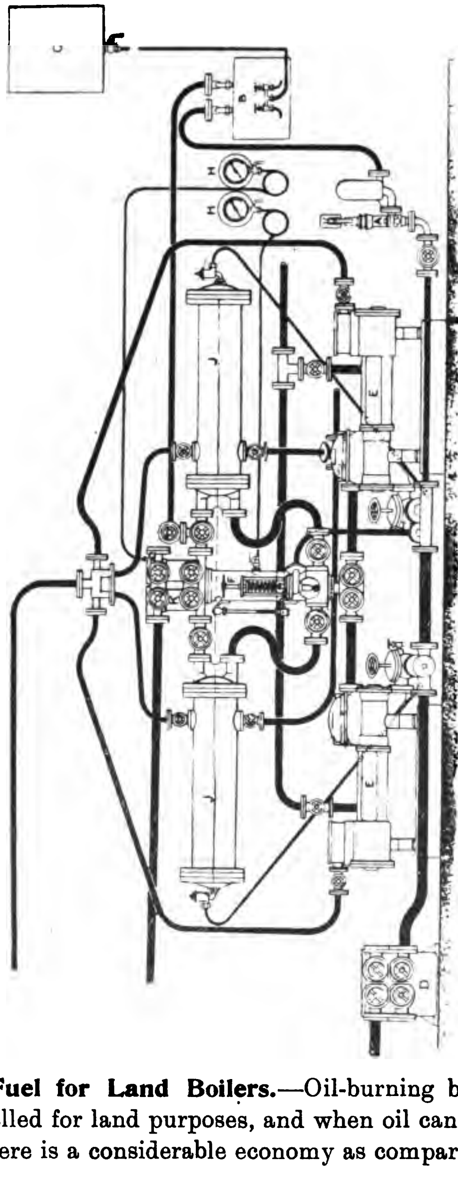


FIG. 18.—Wallsend-Howden system of oil fuel supply.

Liquid Fuel for Land Boilers.—Oil-burning boilers are frequently installed for land purposes, and when oil can be obtained at a low cost there is a considerable economy as compared with coal.

Figs. 18 and 19 illustrate the Wallsend-Howden system as applied to Lancashire type boilers. The various parts and fittings are: A, hand oil-fuel pump; B, auxiliary oil heater; C, supply tank for auxiliary heater; D, duplex suction strainer; E, steam-driven oil-fuel pumps; F, air vessel; G, relief valve; H, pressure gauge; J, main oil-fuel heater; K, duplex discharge strainer; L, thermometer; M, master valves; N, circulating valve; O, distributing valve boxes; P, burners.

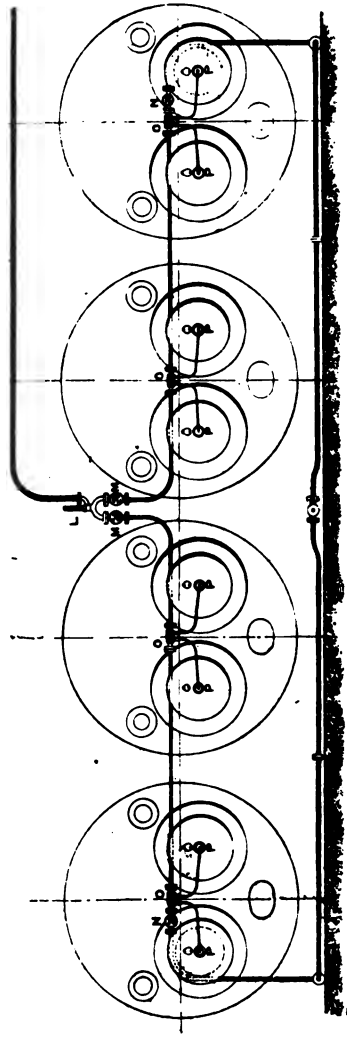


FIG. 19.—Wallsend-Howden system of oil fuel supply.

Instructions for Use of Liquid Fuel. — The following instructions are issued by Messrs. Yarrow for guidance in burning liquid fuel.

Oil Pressure.—The oil pressure will depend upon the amount of oil fuel to be burnt and the number of burners in use, but the pressure should not exceed 180 lbs. per sq. inch at the burners, except in exceptional cases.

When the rate of load varies, the corresponding change in the oil supply should generally be made by altering the oil pressure and not by readjusting the amount of opening of the burners, unless readjustment is necessary to maintain a fine enough or satisfactory oil spray. In some cases it will be desirable to shut off some of the burners at the distributing valve boxes.

The required oil pressure should be maintained as constant as possible. Should it prove unsteady, special attention should be paid to the oil levels in the air vessels attached to the oil-fuel pumps, which should be kept low, but not so low as to disappear from the gauge glasses.

To raise steam initially, the hand oil-fuel pump is used to force the oil through the system until steam is available to operate the steam-driven oil-fuel pumps.

Under normal working conditions, if the oil pressure rises above 150 lbs. per sq. inch, then it is generally necessary to open out a further number of burners; if the pressure falls too low, that is, below about 75 lbs. per sq. inch, then it is necessary to close down a number of burners.

Oil Temperature.—The oil is raised to a suitable temperature to make it thin or fluid enough for efficient spraying, and the temperature of the oil fuel at the burners under working conditions is dependent upon the character, viscosity, and class of the oil to be burned, and varies from a maximum of about 220° Fah., which may be necessary for the heavier oils, to about 80° Fah. for Scotch shale oil fuel. Should the temperature be too high, it may cause pulsation, or unsteady burning in the furnace. On the other hand, too low a temperature will produce smoke or flaming in the uptakes and may also injure the fire-bricks.

Before the steam is admitted to any oil heater, the valves between the heater and the oil fuel pump should be open, and they should remain open until after the steam is shut off on ceasing to use oil fuel.

Air Supply.—The quantity of air required depends upon the amount of liquid fuel to be burnt, and this must be regulated so as to produce :—

1. An amount of smoke which is just visible at the funnel.
2. A flame of about the same size from each burner of the same pattern.

Too small a quantity of air will produce excessive black smoke and tend to produce over-heating of the air distributors. Too large a quantity will produce white smoke and will lessen the efficiency of the boiler. Under ordinary circumstances, the amount of air required for variations in the oil consumed will be obtained by regulating the air pressure in the boiler room, the air doors in the air box to each distributor having been opened as full as possible, provided an efficient flame from each burner is maintained. The flame should, however, be carefully watched, as some readjustment of the air openings may be required.

As soon as steam is raised, the fans should be started, and they should not be stopped again while the burners are working. If the fan stops for any reason, the oil supply to the burners should be shut off at once.

It is best to have all burners which are at work in the boiler room open to the same extent, so that if the proportion of air is correct for one burner it is about correct for all the burners, and the adjustment of air doors for all burners working should be approximately similar.

When a set of burners are shut off, the air doors which supply the air to these burners should be closed also.

Filters and Strainers.—The air filters and strainers should be examined as often as necessary to ensure they are in proper working order, and the pressure gauges fitted on each side of the filters should be frequently noted for indications of clogging. Under ordinary circumstances, one filter only of a pair is sufficient to pass all the oil required, the other being regarded as spare in case the filter in use should become choked. Drain cocks should be fitted to the bottoms of the filters, and the cock on the filter to be cleaned should be opened before the filter cover is removed, so as to release any accumulation of pressure.

Burners.—Each burner should be fixed at its proper distance from the end of its air distributor, and so that its centre line is, as nearly as possible, central to the air distributor. The position at which the air spray issues from the burner should be such that the air distributor is just filled with sufficient flame to keep the air distributor dry without becoming red-hot. If the oil spray leaves the burner at an incorrect position, or is not central with the air distributor, flaming in the air box, or dripping of oil from the air distributor, may result.

Should a burner be extinguished, the cause should be traced, and may be due to any of the following:—

(*a*) Air passing over with the oil from the air vessel on the air pump.

(*b*) Water mixing with the oil, coming from oil-fuel tanks or from leaky heaters.

(*c*) Solid matter choking the burner, either through the filters not removing foreign matter, dirt, etc., or to carbonising of the oil.

(*d*) Too high an oil temperature.

(*e*) Excessive air supply through the air distributor, when the air doors should be shut for a few seconds.

When a burner is choked and cannot be cleared by temporary alteration in the spindle adjustment, it should at once be removed and thoroughly cleaned. Burners should be taken to pieces and cleaned periodically. Cleaning should be carefully carried out so that the outlet holes are not roughened, enlarged or altered in shape. Burners should never be left in place disconnected.

Before lighting a burner after using oil fuel, it should be ascertained that the air boxes and furnaces, etc., are clear of oil and well ventilated, and when carrying out this operation, or relighting a burner, the operator should stand clear of the sight holes.

On easing down or stopping, the oil supply should be reduced before the air supply, so that any inflammable gas may be blown out.

Before lighting up, and while everything is cold, great care should be taken that all the burners are closed.

When lighting up, the "lighting-up heater" is to be well heated up before the "lighting-up" burner is turned on. A burner should on no account be left unattended when lighting-up, as otherwise there is a great danger of flooding with oil.

When the oil is relatively cold it escapes without making any noise, so that there is not the usual indication of the amount passing, and at the same time, the combustion is sluggish, so that a quantity of unburnt oil may collect. Any collection of oil is dangerous, because when the furnace gets hot, this oil may generate gas very quickly, or boil over so as to come into the boiler room.

Air Distributors and Casings.—Air distributors, when in use, should be frequently examined to see that an efficient flame is being produced, and to ascertain whether any deposits are collecting. Deposits of carbon arising from the decomposition of the oil, depending on the quality of the oil and the care of the boiler-room staff, are continually formed on the interior of the air distributors, and these should be removed by suitable cleaning tools before the deposit accumulates to such an extent as to cause trouble. Generally the air distributors require cleaning at intervals of from 20 to 30 minutes. The rate at which the carbon is deposited will be increased if the air supply is insufficient.

Any blocking of the air distributors may cause them to become overheated, flame to appear in the air boxes, dripping of oil, and excessive smoke.

All doors or slides on the air boxes in the way of the air distributors should be kept free and in thorough working order.

Particular attention should be paid to the automatic doors or slides, to ensure that no undue friction or other obstruction will prevent them closing under the influence of a back draught. The bearings for supporting the doors and slides should be occasionally cleaned. The corresponding air doors that should be used should be opened before lighting up.

Oil dripping from air distributors is probably due to one of the following causes and should be immediately attended to.

1. Dirty air distributors.
2. Low oil pressure.
3. Foul burners.

Oil Accumulation and Leakages.—No oil should be allowed to accumulate in the air boxes, bottoms of furnaces, bilges, or on the boiler-room floor plates, etc., and no lighted material should be allowed access to the bilges; after steaming, the bottoms of the furnaces, etc., should be specially examined, and should there be any oil it should be at once removed.

Should a leakage from the oil system to the boiler room, etc., occur at any time, immediate action should be taken to shut off the oil supply by means of the stop valves and to stop the oil pumps.

Fittings.—When oil-fuel fittings are not in use, great care should be taken to keep them clean and in working order; and the air slides and doors and the valves should be frequently worked to ensure that they are efficient.

General.—The smoke observation windows and mirrors should be cleaned once in twenty-four hours, or more often if necessary, and they should be constantly used for the detection of smoke. When watching for smoke, care should be taken that the light fitted for the purpose is sighted and not another.

To shut down when using oil fuel, shut off steam from the oil fuel pumps, thus allowing the burners to use part of the oil remaining in the system and gradually burn out.

Under normal working conditions, water should be delivered to the feed filter tank from the drain collector in connection with each oil-fuel heater; if, however, leakage of oil from a heater is observed in a drain collector, the mixture of oil and water should be discharged into buckets by means of the bill cock on the drain collector, until such time as the stand-by heater can be brought into use. Under normal working conditions the drain valves on the drain collectors should be so regulated that a few inches of water is always showing in the water gauges on the drain collectors.

It is advisable to place oil-tight trays under the oil-fuel fittings, for holding any liquid fuel that may be released when a fitting is opened out.

When using the portable auxiliary oil-fuel heater for lighting up, some loose cotton waste, which has been previously soaked in oil, should be placed in the lamp tray and ignited with a torch, after filling the body of the auxiliary heater with water.

No liquid fuel should be put on board which has not been tested

for flash-point. If the flash-point by close test is below 200° Fah., it should not be used.

The oil-fuel tanks should be examined every day for an accumulation of water at the bottom. This water can be removed by a portable semi-rotary hand pump fitted with a suction pipe going to the bottom of the tank, and delivering into a bucket.

It is most important that the liquid fuel put into the tanks be passed through large filter screens so that it is as clean as possible. The filters in the boiler room are only intended to deal with small impurities in the oil.

It is advisable to have the hand oil-fuel pump always ready for working at a moment's notice, so that if the steam pump stops for any reason, the boilers can continue to supply steam while the steam pump is stopped.

Coal Bunkers.

The following rule can be used to find the holding capacity of coal bunkers :—

$$\text{Rule, } \frac{\text{size of bunker in cubic feet}}{\text{cubic foot per ton}} = \text{capacity in tons.}$$

Or let L = length in feet.
B = breadth in feet.
D = depth in feet.

$$\text{Then, } \quad \frac{L \times B \times D}{\text{cubic foot per ton}} = \text{capacity.}$$

The capacity of bunkers with three widths can be found as follows :—

Rule,

$$\frac{\text{width at top} + \text{middle width} \times 4 + \text{width at bottom}}{6} = \text{mean width.}$$

Example.—Top width of bunker 10 feet 6 inches, middle width 7 feet 9 inches, bottom width 6 feet 6 inches, then

$$\frac{10{\cdot}5 + 7{\cdot}75 \times 4 + 6{\cdot}5}{6} = 8 \text{ feet } 0 \text{ inches mean width.}$$

If the same bunker is 12 feet 6 inches long and 10 feet 3 inches deep, then the holding capacity would be

$$\frac{8 \times 12{\cdot}5 \times 10{\cdot}25}{\text{cubic foot per ton}} = \text{capacity.}$$

Note.—The space occupied by coal varies from about 40 to 45 cub. feet per ton.

Should the former figure be taken for the example given, then the bunker capacity would be

$$\frac{8 \times 12{\cdot}5 \times 10{\cdot}25}{40} = 25{\cdot}62 \text{ tons.}$$

If the latter, then $$\frac{8 \times 12{\cdot}5 \times 10{\cdot}25}{45} = 22{\cdot}8 \text{ tons.}$$

Oil Fuel Stowage.

Oil fuel requires on an average 38 cub. feet per ton for stowage as against an average of 43 cub. feet for coal.

CHAPTER IV.

BOILER MATERIALS.

The materials used in modern boiler construction determine to a large extent the life of the boiler itself; the continual expansion and contraction of plates, the corrosion constantly going on, and the high pressures carried by modern boilers, demand the very best metals procurable.

Cast Iron.—Cast iron was made use of in the construction of the earliest type of boiler to a considerable extent, but owing to its low tensile strength, its lack of elasticity, its brittle and unreliable nature, and the liability of its being very porous, it is now seldom used. Cast iron has a tensile strength varying between 7 and 10 tons per sq. inch, while in compression its strength is in the neighbourhood of 50 tons per sq. inch. The working stress generally allowed for this metal is approximately 1 ton per sq. inch in tension, and 7 tons per sq. inch in compression.

Wrought Iron.—Wrought iron is nearly pure metallic iron, and should contain not more than 0·5 per cent. of impurities. The process of manufacture of wrought iron from pig iron takes two forms. The first process is called refining and is carried out in a calcining furnace; here the impurities are oxidised, the remaining metal forming a slab or plate. In the second process the plate is broken into pieces and taken to a puddling or reverberatory furnace, where it is melted and rabbled with oxide of iron; the carbon in the iron, combining with the oxygen, passes off as CO_2. The particles of malleable iron remaining are formed into blooms, hammered and squeezed, and while still hot rolled into bars. To improve the quality of the iron the bars are cut into short lengths, reheated, hammered, and rolled; this hammering and rolling process can be repeated, the strength and quality of the iron being improved by doing so.

Good wrought iron should have a silky fibre, and a tensile strength of from 25 to 27 tons per sq. inch, an elongation of 25 per cent., and a contraction at the fracture of about 50 per cent., and should be capable of being bent double when cold.

Up to the year 1875, wrought iron was the chief material used in the manufacture of boiler plates, but in recent years wrought iron has been superseded by mild steel, and is only used where it is absolutely necessary to have a welded fastening or stay.

Mild Steel.—Mild steel is the cheapest and most suitable metal for the manufacture of boiler plates; it shows superiority over other metals in respect of the following properties: tensile strength, ductility, toughness, homogeneity and internal soundness.

The mild steel used for boiler plates is made by the open-hearth process; the steel is produced by melting in large reverberatory furnaces a certain quantity of pig iron, and adding oxide of iron in the form of red hæmatite, the necessary amount of carbon being afterwards added in the form of ferro-manganese. The process being very slow, the amount of carbon in the metal can be ascertained by testing a sample piece; this sample is removed from the bulk of the metal by means of a ladle, quenched, broken up, and then tested by the chemist. If the test is satisfactory, the metal is run into ingot moulds, the ingots being afterwards rolled into plates as desired.

Board of Trade Tests for Boiler Plates.—The Board of Trade require the following tests to be made on boiler plates. For furnace plates, and plates exposed to the impact of heat and flame, the tensile strength is not to exceed 30 tons per sq. inch and be not less than 26 tons per sq. inch. For shell plates and general use, 28 tons per sq. inch tensile strength. A test strip is cut from each plate and not less than 25 per cent. of the strips are tested. The elongation allowed is a minimum of 20 per cent. in a length of 10 inches.

Bending Test.—The bending test requires that a parallel strip of plate shall be bent, without cracking, round a curve, the inner radius of which is one and a half times the thickness of the plate. When the plate is exposed to flame impact, then before the bending test, it must have previously been heated to a cherry-red heat and quenched in water at 82° Fah.

Steel Stay Bars.—The following figures give results of tests made upon steel stay bars, and are considered good results:—

Tensile strength . .	27 to 32 tons per sq. inch.
Elongation mean . .	25 per cent. on a length of 10 inches.
Contraction of area .	40 to 50 per cent.

Steel Rivet Bars.—For rivet bars the following results are within the limits of good practice:—

Tensile strength . . .	28 tons per sq. inch.
Elongation	25 per cent.
Contraction of area . . .	50 to 60 per cent.

Fig. 20 shows some unusual tests on steel rivets, and will give a good idea of what can be done to a rivet when made of good quality steel.

Specification for Boiler Plates.—The following specification is recommended by one of the leading boiler insurance companies :—

All boiler plates, angles, and rivets to be of open-hearth steel of British manufacture and free from all laminations, pittings, and other defects. The tensile strength of shell plates to be not less than 26

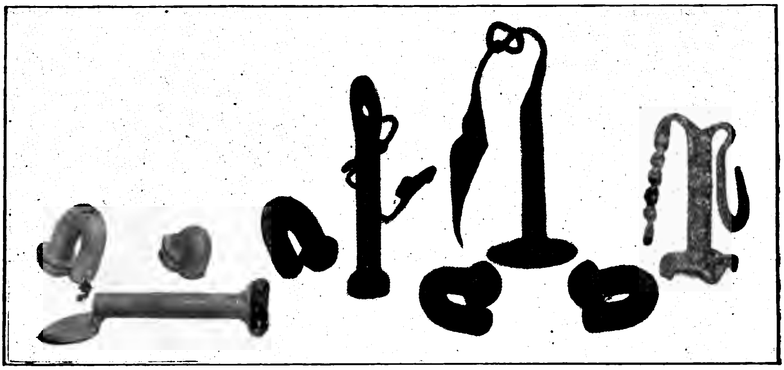


FIG. 20.—Rivet and rivet steel tests.

tons, and not more than 30 tons per sq. inch. The furnace flue tubes and end plates shall have a tensile strength of 24 to 28 tons per sq. inch, the elongation of all test pieces to be not less than 23 per cent. on a length of 8 inches.

The sulphur and phosphorus in the plates to be kept as low as possible, and not to exceed: sulphur, 0·05 per cent.; phosphorus, 0·05 per cent.

The butt straps to be cut from the shell plates, or otherwise all the butt straps to be cut from one plate.

The following tests to be made :—

Four cross test strips from each shell and butt strap plate as follows :—

One from end of the plate for tensile test.
One from same end for cold bending test.
One from opposite end of plate for tensile test.
One from same end for temper bending test.

Three test strips to be cut from each end plate, each flue and furnace plate, and each plate for gusset and butt straps as follows :—

One for tensile test.

One for cold bending test.

One for temper bending test.

The cold bending test to be made by bending the strip while in its normal condition as rolled, and the temper bending test to be made after heating the strip to a blood-red heat and quenching in water at a temperature not exceeding 80° Fah. All strips for bending tests shall stand bending, without cracks, until the sides are parallel, the inner radius being not greater than one and a half times the thickness of the plate.

Testing Plates.

Test specimens should be carefully prepared and free from scratches. Fig. 21 illustrates the form of test piece; the centre part is 9 inches long and exactly 1 inch wide, the centre of this part

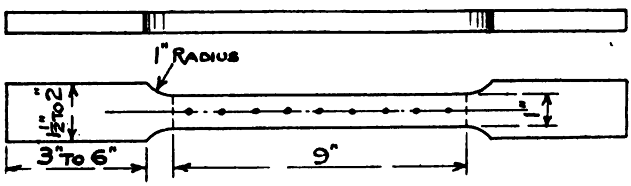


FIG. 21.—Test piece for tensile stress.

being marked out with light centre dot marks at equal distances apart, so as to enable the elongation to be determined.

Test pieces of stay steel and rivet steel are turned circular, the ends being enlarged, and the parallel centre part being turned to a fixed diameter.

Cast Steel.—The difficulty of producing homogeneous castings in steel has prevented the general use of cast steel in boiler work; large percentages of carbon, while increasing the strength of steel, also decreases the ductility of the metal, and make it unsuitable for boiler work.

Nickel Steel.—To illustrate the influence of nickel on steel, we may note that an ultimate tensile strength of 40 tons per sq. inch can be obtained from a 3 per cent. nickel steel having a percentage of carbon as low as 0·175, whereas to obtain this strength in ordinary steel, at least 5 per cent. of carbon would be required, which would render the metal so brittle that it would be unreliable. The ductility of nickel steel is nearly the same as mild steel, and it is found to

resist corrosion much better than the ordinary carbon steel. High temperatures have very little effect on the strength and hardness of nickel steel, therefore it is used to a large extent in the manufacture of modern steam boiler accessories such as stop valves.

Copper.—In many respects copper is much superior to other metals for boiler work, but chiefly owing to its low tensile strength and the rapid decrease of its strength when under the influence of heat, together with the high cost, it is seldom used for general boiler work, except in the case of locomotives.

Copper is a reddish-yellow metal, very ductile and malleable, is a good conductor of heat and resists oxidation. Annealed copper has an ultimate tensile strength of 14 tons per sq. inch, but it rapidly loses its ductility on being worked or hammered to any extent, and requires constant annealing.

Copper is used to a considerable extent in the manufacture of locomotive boilers, more especially for fire boxes and screwed stays. It was also used to a considerable amount in the making of steam pipes, but owing to the many failures of copper steam pipes, its place has been taken by mild steel for all pipes except those of small diameter.

Brass.—Common brass is an alloy of 2 parts of copper and 1 of zinc, with a tensile strength of about 12 tons per sq. inch. It is sometimes used in the construction of boiler fittings such as water-gauge cocks, test cocks, etc.

Muntz Metal.—An alloy of 6 parts copper and 4 parts zinc. This alloy is very strong and tough, having a tensile strength of about 20 tons per sq. inch, and is used in the manufacture of boiler tubes for certain types of locomotives.

Gun Metal.—An alloy of 8 parts copper and 1 tin, with a tensile strength of approximately 13 tons per sq. inch. The majority of boiler fittings, such as gauge cocks, are constructed of gun metal.

Malleable Cast Iron.—This is produced by packing ordinary cast-iron castings in boxes, in close contact with oxide of iron (hæmatite), and heating to a blood-red heat for a period of two to seven days. It is used to a very limited extent in the construction of boiler mountings and seatings.

Effect of Heat upon Materials.—The tensile strength of all metals and alloys is considerably reduced when the temperature is raised to a high point. Alloys, in particular, are seriously affected by an increase of temperature.

It is found that steel and iron begin to loose their tensile strength at about 650° Fah., and alloys of copper and zinc at about 450° Fah.

Strength and Properties of Metals: Definition of Terms.

Compression.—A term used to indicate the state of the particles of a body when a force tends to crush the particles together.

Ductility.—A metal is said to be ductile when it can be drawn and extended by a tensile or pulling force.

Elasticity.—The ability of a metal to return to its original shape after a force has been applied and then released.

Elastic Limit.—If a metal is subjected to a gradually increasing strain, a certain limit is reached beyond which the stresses are no longer proportional to the strains.

Elongation.—The amount by which a piece of metal stretches between two fixed points is called the elongation. It is made up of two parts, one due to the general stretch, the other to the contraction at the point of fracture.

Expansion.—Expansion is usually expressed as a coefficient, which is the amount by which every unit of length expands for every degree of rise in temperature.

Fusibility.—The property of becoming liquid on the application of heat is termed fusibility.

Hardness.—Hardness is the property of the surface of a metal to resist penetration by cutting or scratching. It can be expressed only in relative terms.

Heat Conductivity.—The property possessed in varying degree by metals for transmitting heat along or through them.

Malleability.—The changing of the shape by hammering, pressing, or rolling, without causing fracture.

Shearing.—The shearing strength of a metal is equal to the force which, if applied to a bar of 1 in. section at right angles to the line of axis, would sever it.

Specific Gravity.—The ratio of the weight of a volume of metal to the weight of an equal volume of water is termed the specific gravity.

Specific Heat.—The relative amount of heat absorbed by metals, compared with the heat absorbed by an equal quantity of water when raised through the same temperature.

Stress.—The reaction per unit area, due to pressure or load, or

$$\text{stress} = \frac{\text{force in lbs.}}{\text{area in sq. inches}}.$$

Strain.—The alteration in shape or size, due to the application of force, or

$$\text{strain} = \frac{\text{elongation}}{\text{original length}}.$$

Note.—*Stress* is expressed as a pressure or force in lbs. or tons *strain* is a ratio, or one length divided by another.

Tenacity.—The tenacity of a metal is the strength to resist the effort of stretching or pulling apart.

Tensile Strength.—The force necessary to be applied to a piece of metal along its axis, just to overcome the cohesion of particles and pull it apart.

Toughness.—A metal is said to be tough when it can be bent first in one direction, and then in the opposite, without developing a fracture.

Weldability.—The property possessed by a metal which renders it capable of being joined when in a state of fusion.

HEAT—COEFFICIENT OF EXPANSION FOR VARIOUS METALS.

	Linear Expansion.	Surface Expansion.	Cubic Expansion.
Cast iron	·00000617	·00001234	·00001850
Copper	·00000955	·00001910	·00002864
Brass	·00001037	·00002074	·00003112
Bar iron	·00000686	·00001372	·00002058
Steel	·00000599	·00001198	·00001798
Zinc	·00001634	·00003268	·00004903
Tin	·00001410	·00002820	·00004229
Mercury	·00003334	·00006668	·00010010

Example.—If a wrought-iron bar is 22 feet long and is heated from 70° to 300°, find how much it will have lengthened.

$$22 \times (300 - 70) \times \cdot 00000686 = \cdot 0347116 \text{ feet} = \cdot 41654 \text{ inch.}$$

Answer. ·416 inch.

Melting-point of Metals.

	Fah.		Fah.
Aluminium	1218°	Nickel	2600°
Antimony	1160°	Platinum	3200°
Brass	1750°	Silver	1750°
Bronze	1670°	Steel	2500°
Copper	1940°	Tin	440°
Iron, cast	2300°	Tungsten	5400°
„ wrought	2900°	Vanadium	3200°
Lead	620°	Zinc	780°

CHAPTER V.

BOILER CONSTRUCTION.

Strength of Cylindrical Boiler Shells.—When steam is admitted to a cylindrical vessel, it exerts the same amount of pressure in every direction, and the plates become subjected to a tensile stress both longitudinally and circumferentially, the intensity of which may rupture the shell, as shown at A and B in Fig. 22.

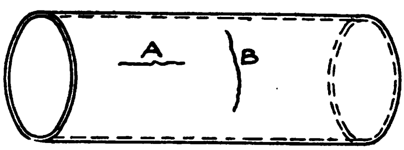


FIG. 22.—Illustration of shell rupture.

The strongest form of boiler shell is a true sphere; here the stresses under internal steam are equal in all directions, and the sphere would tend to become larger, all parts being of equal strength. The difficulties to be contended with in constructing a spherical vessel are great, and the area obtained for a given volume is small. For these reasons boilers are made cylindrical in shape, and to counteract the loss in strength the ends are either dished or stayed.

Stress.—The circumferential stress on any part of a cylindrical

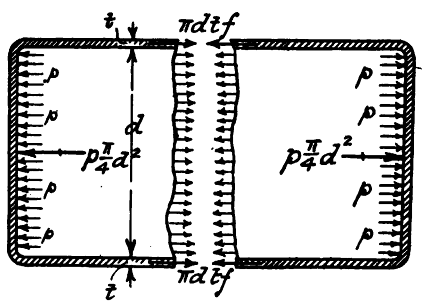


FIG. 23.—Diagram showing stresses on circumferential seam of boiler shell.

vessel is due to the pressure exerting itself on the end plates as shown in Fig. 23, and this can be calculated as follows :—

Let p = pressure in lbs. per sq. inch.
d = diameter of boiler in inches.
t = thickness of plate in inches.

Then total pressure on end plate $= \frac{\pi d^2}{4} \times p$.

Area of metal to resist rupture $= \pi dt$.

Then stress $= \frac{\pi d^2}{4} \times p \div \pi dt = \frac{pd}{4t}$.

Example.—A boiler shell is 8 ft. in diameter, thickness of metal 0·75 inch, steam pressure 150 lbs. per sq. inch. Find the circumferential stress.

$$\text{Stress} = \frac{pd}{4t} = \frac{150 \times 96}{4 \times 0{\cdot}75} = 4800 \text{ lbs. per sq. inch.}$$

The longitudinal stress can be better understood from the diagram (Fig. 24). Here the tension acting on one side is in opposition

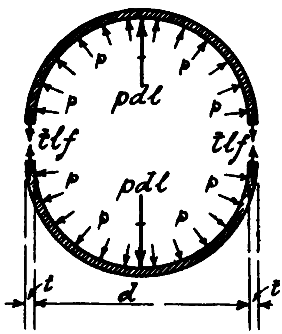


FIG. 24.—Diagram showing stresses on longitudinal seam of boiler shell.

to an equal force acting on the other, and exerting a pressure at $p, p, p,$ equal to pressure × length × diameter, or $p \times l \times d$. The area of metal to resist rupture is the thickness of metal × length × 2, or $t \times l \times 2$.

The width of the metal section need not be taken into account, as the tension due to increased length is balanced by increase of metal, and therefore the stress is equal to $dp \div 2t$.

The stress on the circumference of a cylindrical shell is $\frac{dp}{4t}$, and longitudinally it is $\frac{dp}{2t}$; the stress on the circumferential seams being half that on the longitudinal seams, the tendency to rupture longitudinally is twice as great as the tendency to rupture circumferentially.

If the shell of a cylindrical boiler is of the same thickness throughout, then it is twice as strong transversely as it is longitudinally, and for this reason the thickness of a boiler shell is calculated from the formula for longitudinal rupture, and the longitudinal joints made stronger than the circumferential ones.

Working Pressure.—The working pressure per sq. inch for cylindrical boiler shells can be found by the following formula :—

Let S = minimum tensile strength of plate in lbs. per sq. inch.
  °/ₒ = percentage strength of longitudinal joint.
  T = thicknesses of plate in inches.
  F = factor of safety.
  D = maximum inside diameter of shell in inches.

$$\text{Then working pressure} = \frac{S \times {}^{\circ}/_{\circ} \times 2T}{F \times D}.$$

The factor of safety is taken as from 5 to 6 for boilers newly made and of good construction.

To find the percentage strength of the joint, the Board of Trade issue the following rules, which are used in conjunction with the formula for finding the working pressure.

Let p = greatest pitch of rivets in inches longitudinally.
  d = diameter of rivets in inches.
  a = area of one rivet in sq. inch.
  n = number of rivets in length of joint equal to p.
  S_1 = minimum tensile strength of plates in tons per sq. inch.
  S_2 = shearing strength of rivets in tons per sq. inch, being 23 for steel and 17·5 for iron.
  C = 1 for rivets in single shear, or 1·875 for double shear.
  r = percentage of plate left between holes in greatest pitch.
  R = percentage of value of rivet section.
  R_1 = percentage of combined plate and rivet section.

The percentage strength of joint is found from the following equations, taking the least value for r, R, or R_1 as the case may be :—

$$\frac{100(p - d)}{p} = r.$$

$$\text{For steel plates} = \frac{100 \times S_2 \times a \times n \times C \times F}{4{\cdot}5 \times S_1 \times p \times T} = R.$$

$$\text{For iron plates} = \frac{100 \times a \times n \times C}{p \times T} = R.$$

For riveted joints in which every alternate rivet is omitted from the outer row, or from the outer and inner rows :—

$$\frac{100(p - 2d)}{p} + \frac{R}{n} = R_1.$$

Furnaces.

The furnace arrangement of an ordinary type of horizontal boiler is shown in Fig. 25. The furnace front is of mild steel and fits into the boiler end plate, being held in position by suitable bolts.

The door is of cast iron, arranged with an inner perforated plate to distribute the air, and provided with a sliding grid which can be

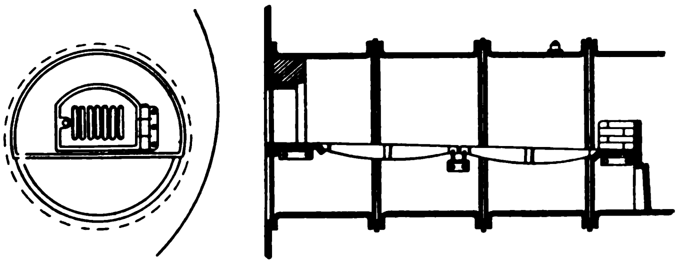


FIG. 25.—Section through furnace of Lancashire boiler.

moved by means of the door handle. The grid admits air through the furnace door and above the fire-bars.

A dead plate of cast iron is connected to the furnace front, and acts as a support to the front ends of the fire-bars. The top of the dead plate is level with the tops of the fire-bars, the back edge

FIG. 26.—Marine type furnace door.

being levelled off so as to allow the bars to drop into position and give room for expansion.

Bearer bars are bolted to steel brackets riveted to the furnace plates, to support the inner ends of both rows of fire-bars, and a bearer is secured at the back end of the furnace to support the brick bridge and the back ends of the fire-bars.

Fire-bars.—Fire-bars are made in various forms to suit the class of fuel being burned. The length of bar when in two sets is usually

3 feet, the inner ends being lipped to drop on the inner bearer bars, so that any expansion takes place on the bridge bar or dead plate.

Furnace doors of marine boilers are usually constructed as shown in Fig. 26. Here the doors are fitted with weights which give a self-

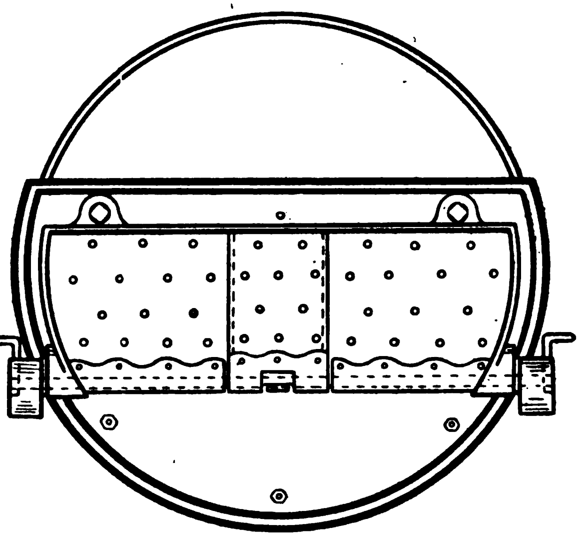


Fig. 27.—Furnace door in three parts.

closing door. Another type of furnace door is shown in Fig. 27. This door is divided into three parts; the raising of the right or left-hand door also lifts the centre door, and lowering the centre door closes the side doors.

Bridges.—The ordinary type of bridge is built up with fire-brick arranged on the bridge plate to within about 9 inches of the furnace crown. The space above the bridge should have a cross-sectional area of from $\frac{1}{6}$ to $\frac{1}{8}$ the area of fire-grate.

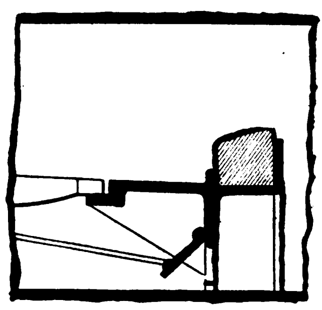


Fig. 28.—Furnace bridge.

To get a better combustion by admitting air to the back of the fire, a bridge casting constructed in box form, as shown in Fig. 28, is sometimes adopted. The box forms an air chamber having a door in front and a perforated plate at the back. A door is arranged in the lower part of the bridge plate to admit air to the bridge box and from thence to the back of the fire as desired.

Another method, adopted by Messrs. J. Neil & Co. of Glasgow, is shown in Fig. 29. Air is always admitted through openings *c* in the base plate to the narrow slots *d*, which are covered with fire.

Air may also be admitted through perforations *e* in the rear section of the plate, passing into the combustion chamber through

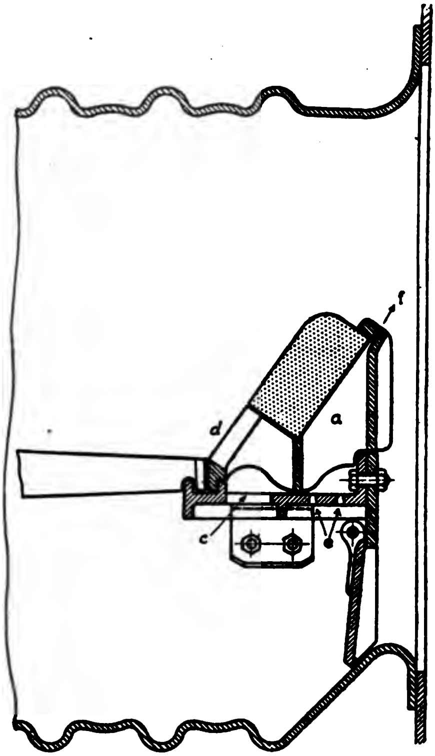


FIG. 29.—Furnace bridge for admitting air.

narrow openings *f*, but these latter may be dispensed with and the bridge made airtight.

Furnace Tubes.

Boiler furnace tubes are subjected to an external pressure, and should be perfectly cylindrical. The pressure exerts a crushing action, and the tendency is to buckle or distort the tube in any part which is in any way not of true cylindrical form.

The earliest form of boiler tube consisted of a plain cylindrical tube, riveted at one end to an angle-iron ring, and at the other connected by a simple lap joint to the next ring of the tube. An im-

provement on this was the bowling ring shown in Fig. 30; this considerably stiffened the tube and allowed for expansion. A further

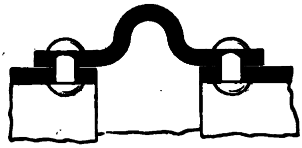


FIG. 30.—Bowling hoop for boiler flue plates.

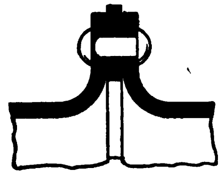


FIG. 31. — Adamson's ring for connecting boiler flue plates.

development was the Adamson joint shown in Fig. 31; this design consists of flanging the two plates and fitting between the flanges

FIG. 32.—Fox's corrugated furnace.

a caulking ring, an arrangement which permits of expansion, as the joint is elastic, and also provides a method of strengthening the tube.

FIG. 33.—Purves' flue.

Furnace tubes should be as thin as possible in order that the heat transmission should be as rapid as possible. Plain furnaces for high pressures, required to be of excessive thickness, and corrugated

FIG. 34.—Morrison's furnace.

furnaces have now been generally adopted. These furnaces are much stronger than plain furnaces, and higher pressures can be used without a corresponding increase in the thickness of the metal.

FIG. 35.—The "suspension bulb" furnace.

Corrugated furnaces are made in many forms. Fig. 32 shows Fox's; Fig. 33, Purves'; Fig. 34, Morrison's; and Fig. 35, the Suspension Bulb.

The advantages of the corrugated flue over the plain tube are:—

Greater resistance to collapse.
Increased heating surface.
Easy scaling.
Greater elasticity.

Formulæ for Working Pressures of Plain Circular Steel Furnaces.

To find the working pressure for plain circular steel furnaces with the longitudinal joints welded, or made with a butt-strap double-riveted, or double butt-straps single-riveted, the following Board of Trade formula can be used:—

Working pressure

$$= \frac{9900 \times \text{square of the thickness of the plate in inches}}{(\text{length in feet} + 1) \times \text{diameter in inches}}.$$

This formula is used only when the result does not exceed that found by the following calculation:—

$$\text{Working pressure} = \frac{9900 \times \text{thickness in inches}}{\text{diameter in inches}}.$$

Furnaces with Adamson Rings.—The Board of Trade formula for horizontal furnaces welded longitudinally with flanged ends riveted together with a caulking ring, can be found from the following formula, provided the length in inches over flanges does not exceed $(120t - 12)$:—

Let t = thickness of plate in inches.
l = length over flanges in inches.
D = outside diameter of furnace in inches.

$$\text{Then working pressure per sq. inch} = \frac{9900 \times t}{3 \times D}\left(5 - \frac{l + 12}{60 \times t}\right).$$

Corrugated Furnaces.—When new corrugated furnaces are machine made and practically true cylinders, the working pressure is found by the following formula when plates are not less than $\frac{5}{16}$ inch thick:—

Let t = thickness in inches.
D = least outside diameter.
WP = working pressure per sq. inch.

$$\text{Then} \quad WP = \frac{14000 \times t}{D}.$$

Tensile strength of plate is 26 to 30 tons per sq. inch.

The least outside diameter is taken, as shown in Fig. 36, which gives a section of the Deighton furnace.

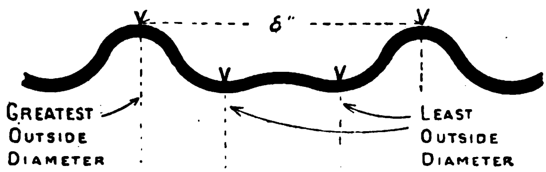


FIG. 36.—Deighton's patent flue.

Riveting.

When one plate overlaps and is riveted to another, as in Fig. 37, it is termed a **single-riveted lap joint.** The efficiency of the joint, and the pitch of rivets for various thicknesses of plates, is given in Table 3.

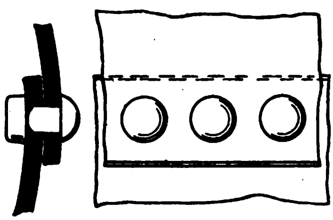


FIG. 37.—Single-riveted lap joint.

When the amount of lap is increased, and a second row of rivets added, as in Fig. 38, it is called a **double-riveted lap joint.** Table 4 gives the efficiency, etc., of this joint. A still further increase in the amount of lap, and a third row of rivets, make a triple-riveted lap joint, the efficiency of which is shown in Table 5.

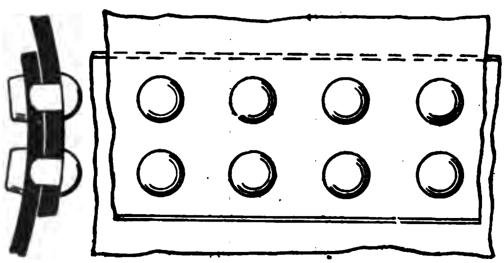


FIG. 38.—Double-riveted lap joint.

When rivets are placed so that those of one row are opposite the spaces of another row, it is termed **zigzag riveting.** If the rivets are placed opposite each other, it is called **chain riveting.**

When the plates to be riveted are kept in the same plane, and a

TABLE 3.

SINGLE RIVETED LAP JOINTS

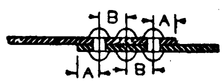
Thickness of Plate Inches	Diameter of Rivet Hole Inches	Efficiency of Joint Per Cent	Pitch of Rivets Inches	Dimension A Inches
1/4	11/16	60.7	1 3/4	1 1/16
9/32	11/16	55.5	1 3/4	1 1/16
5/16	13/16	57.5	2 1/8	1 1/4
11/32	13/16	52.3	2 1/8	1 1/4
3/8	15/16	58.3	2 1/4	1 7/16
13/32	15/16	55.6	2 1/4	1 7/16
7/16	1 1/16	57.5	2 1/2	1 5/8
15/32	1 1/16	55.7	2 1/2	1 5/8
1/2	1 1/16	52.2	2 1/2	1 5/8

TABLE 4.

DOUBLE RIVETED LAP JOINTS

Thickness of Plate Inches	Diameter of Rivet Hole Inches	Efficiency of Joint Per Cent	Pitch of Rivets Inches	Dimension A Inches	Dimension B Inches
1/4	11/16	72.5	2 1/2	1 1/16	1 3/4
9/32	11/16	72.5	2 1/2	1 1/16	1 3/4
5/16	13/16	71.7	2 7/8	1 1/4	1 7/8
11/32	13/16	71.7	2 7/8	1 1/4	1 7/8
3/8	15/16	70.0	3 1/8	1 7/16	2
13/32	15/16	70.0	3 1/8	1 7/16	2
7/16	1 1/16	68.5	3 3/8	1 5/8	2 1/8
15/32	1 1/16	69.6	3 1/2	1 5/8	2 1/8
1/2	1 1/16	69.6	3 1/2	1 5/8	2 1/8

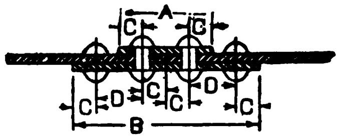
TABLE 5.



TRIPLE RIVETED LAP JOINTS

Thickness of Plate Inches	Diameter of Rivet Hole Inches	Efficiency of Joint Per Cent	Pitch of Rivets Inches	Dimension A Inches	Dimension B Inches
1/4	11/16	77.0	3	1 1/16	1 7/8
9/32	11/16	77.0	3	1 1/16	1 7/8
5/16	11/16	78.8	3 1/4	1 1/16	1 7/8
11/32	13/16	75.0	3 1/4	1 1/4	2 1/8
3/8	13/16	75.0	3 1/4	1 1/4	2 1/8
13/32	13/16	75.0	3 1/4	1 1/4	2 1/8
7/16	15/16	75.0	3 3/4	1 7/16	2 3/8
15/32	15/16	75.0	3 3/4	1 7/16	2 3/8
1/2	15/16	75.0	3 3/4	1 7/16	2 3/8

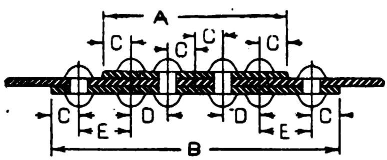
TABLE 6.



DOUBLE RIVETED BUTT STRAP JOINTS

Thickness of Plate Inches	Diameter of Rivet Hole Inches	Efficiency of Joint Per Cent	Long Pitch Inches	Short Pitch Inches	Thickness of Strap Inches	Width of Outside Strap A Inches	Width of Inside Strap B Inches	Dimension C Inches	Dimension D Inches
1/4	11/16	82.8	4	2	1/4	4 1/4	8 3/8	1 1/16	2 1/16
9/32	11/16	81.5	4	2	1/4	4 1/4	8 3/8	1 1/16	2 1/16
5/16	13/16	81.9	4 1/2	2 1/4	9/32	5	9 7/8	1 1/4	2 7/16
11/32	13/16	81.9	4 1/2	2 1/4	9/32	5	9 7/8	1 1/4	2 7/16
3/8	13/16	81.9	4 1/2	2 1/4	5/16	5	9 7/8	1 1/4	2 7/16
13/32	13/16	81.0	4 1/2	2 1/4	5/16	5	9 7/8	1 1/4	2 7/16
7/16	15/16	81.2	5	2 1/2	3/8	5 3/4	11 3/8	1 7/16	2 13/16
15/32	15/16	81.2	5	2 1/2	3/8	5 3/4	11 3/8	1 7/16	2 13/16
1/2	15/16	81.2	5	2 1/2	7/16	5 3/4	11 3/8	1 7/16	2 13/16
17/32	1 1/16	80.6	5 1/2	2 3/4	7/16	6 1/2	12 7/8	1 5/8	3 3/16
9/16	1 1/16	80.6	5 1/2	2 3/4	7/16	6 1/2	12 7/8	1 5/8	3 3/16

TABLE 7.



TRIPLE RIVETED BUTT STRAP JOINTS

Thickness of Plate Inches	Diameter of Rivet Hole Inches	Efficiency of Joint Per Cent	Long Pitch Inches	Short Pitch Inches	Thickness of Strap Inches	Width of Outside Strap A Inches	Width of Inside Strap B Inches	Dimension C Inches	Dimension D Inches	Dimension E Inches
1/4	11/16	86.2	5	2 1/2	1/4	8	12 1/8	1 1/16	1 7/8	2 1/16
9/32	11/16	86.2	5	2 1/2	1/4	8	12 1/8	1 1/16	1 7/8	2 1/16
5/16	13/16	87.0	6 1/4	3 1/8	1/4	9	13 7/8	1 1/4	2	2 7/16
11/32	13/16	87.0	6 1/4	3 1/8	1/4	9	13 7/8	1 1/4	2	2 7/16
3/8	13/16	87.5	6 1/2	3 1/4	5/16	9	13 7/8	1 1/4	2	2 7/16
13/32	13/16	87.5	6 1/2	3 1/4	5/16	9	13 7/8	1 1/4	2	2 7/16
7/16	15/16	86.1	6 3/4	3 3/8	3/8	10	15 5/8	1 7/16	2 1/8	2 13/16
15/32	15/16	86.6	7	3 1/2	3/8	10	15 5/8	1 7/16	2 1/8	2 13/16
1/2	15/16	87.5	7 1/2	3 3/4	7/16	10	15 5/8	1 7/16	2 1/8	2 13/16
17/32	15/16	87.5	7 1/2	3 3/4	7/16	10	15 5/8	1 7/16	2 1/8	2 13/16
9/16	1 1/16	86.2	7 3/4	3 7/8	7/16	11 1/8	17 1/2	1 5/8	2 5/16	3 3/16
19/32	1 1/16	86.2	7 3/4	3 7/8	1/2	11 1/8	17 1/2	1 5/8	2 5/16	3 3/16
5/8	1 1/16	86.0	7 3/4	3 7/8	1/2	11 1/8	17 1/2	1 5/8	2 5/16	3 3/16
21/32	1 1/16	85.4	7 3/4	3 7/8	1/2	11 1/8	17 1/2	1 5/8	2 5/16	3 3/16
11/16	1 3/16	84.6	7 3/4	3 7/8	17/32	12	19 1/8	1 13/16	2 3/8	3 9/16
23/32	1 3/16	84.0	7 3/4	3 7/8	17/32	12	19 1/8	1 13/16	2 3/8	3 9/16
3/4	1 3/16	83.9	8	4	9/16	12	19 1/8	1 13/16	2 3/8	3 9/16

cover joint placed above or below, as shown in Fig. 39, the joint is termed a **butt-strap joint,** and when an extra strap is added, as seen in Fig. 40, it is called a **double butt-strap joint.** The efficiency

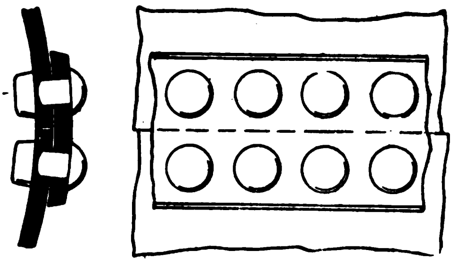


FIG. 39.—Butt joint single-riveted single cover strap.

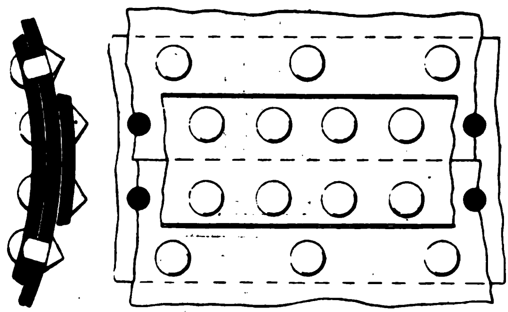


FIG. 40.—Double-riveted butt-strap joint.

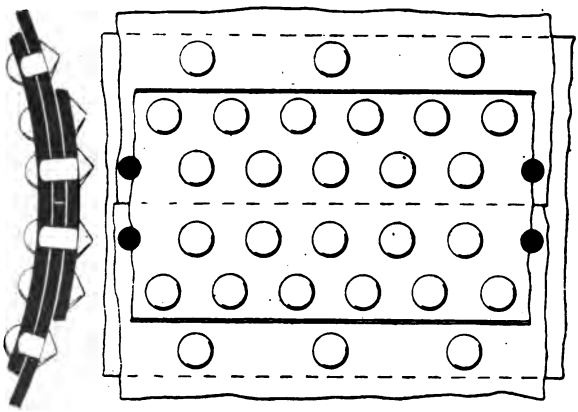


FIG. 41.—Triple-riveted butt-strap joint.

of double-riveted butt-strap joints for various thickness of plates is given in Table 6.

A treble-riveted butt-strap joint is shown in Fig. 41, and Table 7 gives the efficiency, etc.

Rivets.—The various forms of rivets are shown in Fig. 42. Rivet diameters for various thicknesses of plate vary from $d = 1{\cdot}2\sqrt{t}$ to $d = 1{\cdot}4\sqrt{t}$, in which t is the thickness of the plate and d diameter of rivet. To form the head, the rivet should have a length in ex-

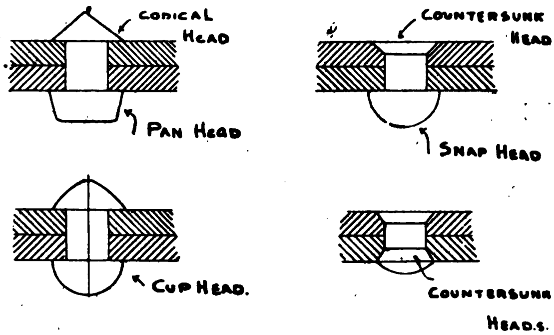


FIG. 42.—Rivets.

cess of the thickness of the plate equal to about three-fourths the diameter for a counter-sunk head, and from 1·3 to 1·7 times the diameter for ordinary riveting.

Flat Surfaces.

The working pressure in lbs. per sq. inch on plates forming flat surfaces can be calculated from the formula—

$$\text{Working pressure} = \frac{C \times (t + 1)^2}{s - 6},$$

t being thickness of plate in sixteenths of an inch.
S „ surface supported in sq. inches.
C „ constant depending on the following conditions:—

C = 240 when plates are not exposed to impact of heat or flame, stays fitted with nuts on both sides of plates, and doubling strips, not less in width than two-thirds the pitch of the stays and of the same thickness as the plates, securely riveted to the outside of the plates they cover.

C = 210 when plates are not exposed to impact of heat or flame, stays fitted with nuts on both sides of plates, and washers, not less in diameter than two-thirds the pitch of the stays, and of the same thickness as the plates, securely riveted to the outside of the plates they cover.

C = 165 when plates are not exposed to impact of heat or flame, stays fitted with nuts on both sides of plates, and washers outside the plates at least three times the diameter of stay, and two-thirds the thickness of plates they cover.

C = 150 when plates are not exposed to impact of heat or flame, stays fitted with nuts on both sides of plates.

C = 112·5 when tube plates not exposed to direct impact of heat or flame, stays fitted with nuts.

C = 77 when tube plates not exposed to direct impact of heat or flame, stay tubes screwed into plates and expanded.

C = 77 when plates not exposed to impact of heat or flame, stays screwed into plates and riveted over.

C = 75 when plates are exposed to impact of heat, with steam in contact with plates, stays fitted with nuts and washers, the latter being at least three times the diameter of stay, and two-thirds thickness of plates they cover.

C = 67·5 when plates exposed to impact of heat, with steam in contact with plates, stays fitted with nuts only.

C = 100 when plates exposed to impact of heat or flame, with water in contact with plates, and stays screwed into plates and fitted with nuts.

C = 66 when plates exposed to impact of heat or flame, with water in contact with plates, stays screwed into plates and having ends riveted over to form substantial heads.

C = 39·6 when plates exposed to impact of heat with steam in contact with plates, stays screwed into plates and having ends riveted over to form substantial heads.

Circular Flat Plates.—When a circular flat end is bolted or riveted to a cylindrical shell, S in the formula may be taken as the area of the square inscribed in the circle passing through the centres of the bolts or rivets securing the end, provided the angle ring or flange is of sufficient thickness.

Stress on Steel Tube Plates.

Let D = least horizontal distance between centres of tubes in inches.

d = inside diameter of ordinary tubes in inches.

t = thickness of tube plate in inches.

W = width of combustion-box in inches between tube plate and back of fire-box, or distance between combustion-box tube plates when boiler is double-ended, and the box common to the furnaces at both ends.

To find the working pressure the following formula can be used :—

$$\frac{(D - d)t \times 28000}{W \times D}.$$

Girders.—When solid rectangular girders, as shown in Fig. 43, are used to support the tops of combustion-boxes, the following

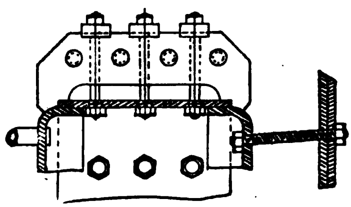


FIG. 43.—Bridge or girder stay for top of fire-box.

formula can be used for finding the working pressure to be allowed on the girders, provided that they are not subjected to a greater temperature than the ordinary heat of steam, and in the case of combustion chambers, that the ends are properly bedded to the edges of the tube plate and the back plate of the combustion-box :—

Let W = width of combustion-box in inches.

P = pitch of supporting bolts in inches.

D = distance between the girders from centre to centre in inches.

L = length of girder in feet.

d = depth of girder in inches.

t = thickness of girder in inches.

N = number of supporting bolts.

$C = \frac{N \times 1320}{N + 1}$ when the number of bolts is odd.

$C = \frac{(N + 1)1320}{N + 2}$ when the number of bolts is even.

Then Board of Trade formula is:—

$$\text{Working pressure in lbs. per sq. inch} = \frac{C \times d^2 \times t}{(W - P)D \times L}.$$

Boiler Tubes.

Boiler smoke tubes are made from iron and steel for marine work, and for land purposes from copper and brass as well. Iron tubes are as a rule lap-welded, while steel tubes are more frequently solid drawn. In H.M. Navy the outside diameter of the tubes are from $2\frac{1}{2}$ to 3 inches, while for land purposes and in the mercantile marine they vary from $1\frac{3}{4}$ to 4 inches.

Tubes vary in thickness according to their outside diameter, length, and working pressure, and are swelled out about $\frac{1}{16}$ inch at the smoke-box end, to facilitate withdrawal. The spacing of tubes in

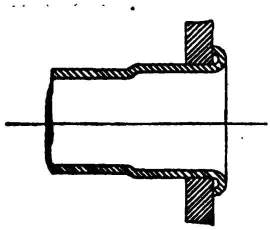


FIG. 44.—Beaded tube.

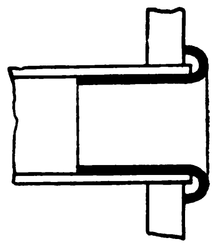


FIG. 45.—Tube fitted with ferrule.

mercantile marine boilers is usually equal to 1·4 times the diameter, arranged in horizontal and vertical rows.

To prevent burning and wasting of tube ends, tubes are sometimes beaded over in the back plate, as shown in Fig. 44, or else fitted with a protecting ferrule, as seen in Fig. 45. The ferrules are driven in tightly, and form a protection for the end of the tube and a portion of the tube plate from the action of the flame.

Serve Tubes.—These tubes are constructed with longitudinal ribs, as shown in Fig. 46; they give an additional heating surface, and allow for a better circulation of the hot gases.

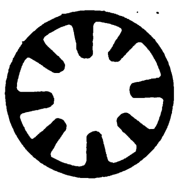


FIG. 46.—Section of serve boiler tube.

Water Tubes.—Tubes for water-tube boilers are made from solid drawn steel of a tensile strength of about 25 tons per sq. inch, with an elongation of 25 per cent. in 8 inches.

Experiments by Mr. Yarrow show that a tube $1\frac{3}{4}$ inch external diameter and $\frac{5}{32}$ inch thick expanded into a tube plate, requires $13\frac{1}{2}$ tons, equal to a stress of 17

tons per sq. inch of the section of the metal, to pull the tube out of the tube plate, and in doing so the tube stretched 5⅝ inches.

Stay Tubes.—Stay tubes are used to support the tube plates of boilers of the marine and locomotive types. The outside diameter is generally the same as that of the plain tube, and the ends are provided with about 12 threads per inch, one end of the tube being thickened

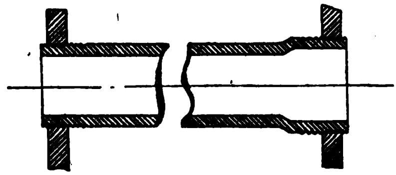


FIG. 47.—Section of screwed stay tube.

so that the inner thread of the tube will pass through the hole in the front tube plate. The stay tube is screwed into both tube plates, as shown in Fig. 47, and is secured either by expanding the ends of the tubes or by means of nuts and washers.

Tube Expanders.—Fig. 48 shows a tube expander. This tool consists of a steel body holding hardened steel rollers, and provided

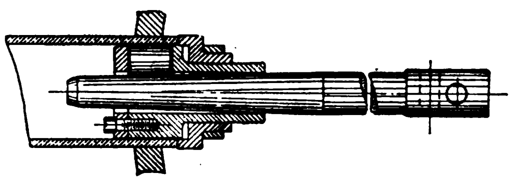


FIG. 48.—Section of boiler tube expander.

with a taper mandrel with holes in the head, to take a tommy bar. It is used for expanding tubes in tube plates and headers.

Staying Boilers.

The type of stay to be used for a particular purpose depends upon several factors. Flat surfaces in particular are stayed and supported by several methods, each method being decided upon only after the stresses have all been taken into account. No fixed rules are applicable to all cases, it being necessary to consider carefully the shape, size, and stiffness of the plate to be stayed, the amount of support it receives from adjacent plates, and the suitability of the particular stay to take up the force exerted by the plate. Another question of importance is the accessibility to the boiler after the stay has been fixed; this is particularly important when the boiler is of small size.

The simplest form of stay used for supporting flat end plates

consists of a plain tie rod running from plate to plate, made of steel, and fastened at either end by means of nuts and washers, as seen in Fig. 49. To allow for removal when cleaning, the ends of the stay rods are sometimes fitted as shown in Fig. 50.

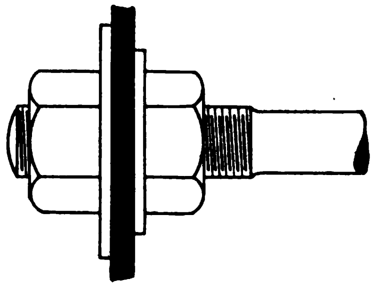


FIG. 49.—End of longitudinal stay rod.

Locomotive fire-boxes and combustion chambers of marine boilers are secured by short screwed stay bolts, as shown in Fig. 51. In marine boilers the stay bolts, instead of being riveted over, are

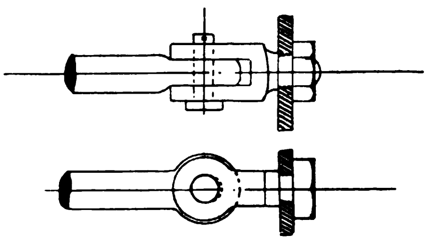


FIG. 50.—Knuckle joint stay.

more often secured by means of nuts and washers, as in Fig. 52. The inner threads of screw stays are now generally turned off, as it is found that a stay bolt with a smooth surface will resist corrosion

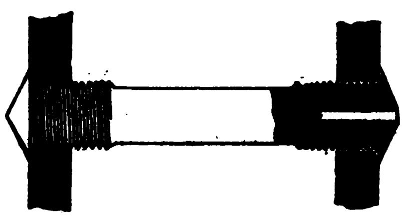


FIG. 51.—Screwed stay with hole for detecting escape of steam or water.

and is less liable to fracture than a fully threaded one. A hole is sometimes drilled up one end of the bolt, in which case a fracture of the bolt will be indicated by an escape of steam through the hole.

Stress Allowed on Stay Bolts.—The stresses produced on stay bolts of the locomotive fire-box type, are chiefly caused by the expansion and contraction of plates, and may be tensile or bending; the latter is probably the cause of fracture in most cases.

The stress allowed on screwed stays is as follows:—

Iron stay not welded or worked in the fire	7000 lbs. per sq. inch.
Iron stays which have been welded . .	5000 ,, ,, ,, ,,
Steel stays	8000 ,, ,, ,, ,,

The size of stay must be calculated on the area of the bottom of the thread at the smallest section of the stay. Welded iron stays are

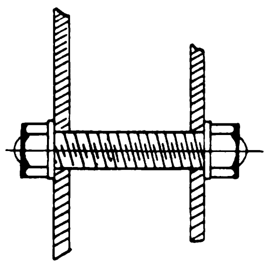


FIG. 52.—Marine pattern fire-box stay.

now very seldom used, and welded steel stays are not allowed by the Board of Trade under any circumstances.

Gusset Stays.—Cylindrical boilers of the Lancashire type have the end plates supported by gusset stays of diagonal plates, as shown in Fig. 53. Another form of stay, fitted to support flat end plates,

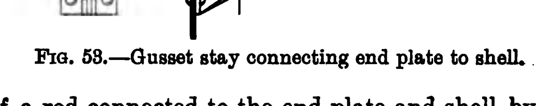


FIG. 53.—Gusset stay connecting end plate to shell.

consists of a rod connected to the end plate and shell by pins which pass through angle pieces riveted to the end and shell plates. This arrangement, together with a bracing provided with specially forged ends, will be seen in Fig. 54, which gives a horizontal section of a horizontal return tube boiler. The stays for the back tube plate

will be seen in Fig. 55. Another form of stay bracing will be seen in Fig. 56.

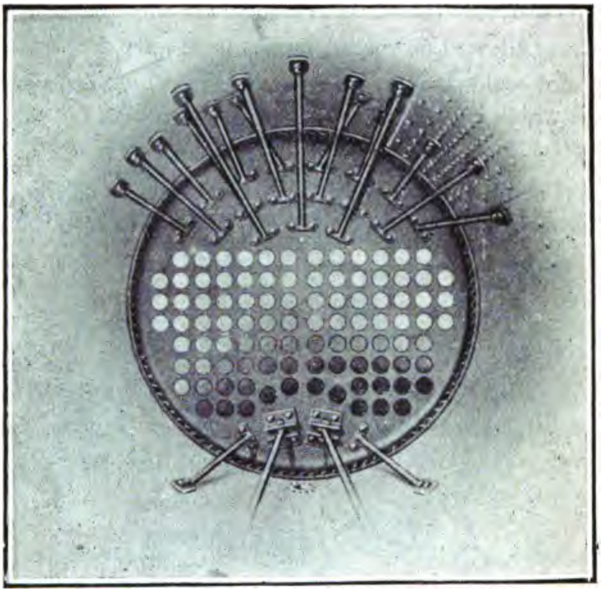


FIG. 54.—Bracings for supporting flat surfaces.

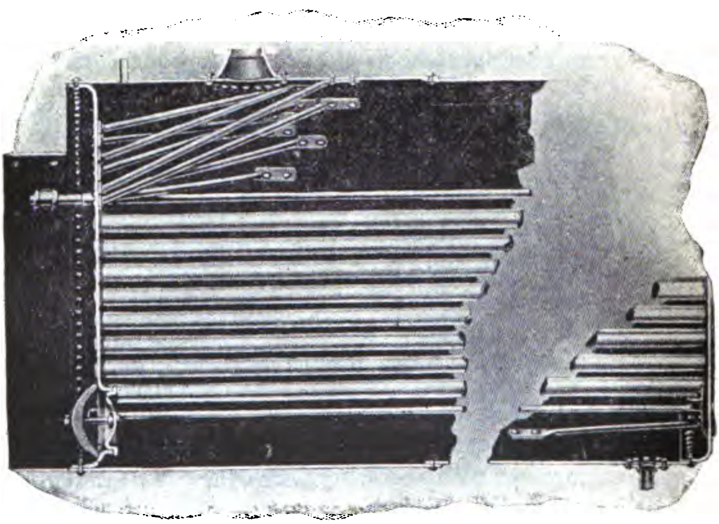


FIG. 55.—Stays for supporting back tube plate.

Pressure on Flat Plates.

The following formula can be used to find the pressure for flat plates :—

Let 80 = constant.
6 = constant.
t = thickness of plate in sixteenths of an inch.
S = pitch of stays squared (surface supported).

$$\text{Then safe pressure} = \frac{80 \times (t + 1)^2}{S - 6} \text{ lbs. per sq. inch.}$$

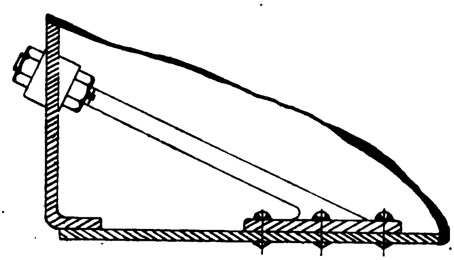


FIG. 56.—Diagonal stay for connecting plates at right angles.

Pitch of Stays.

Let 80 = constant.
6 = constant.
t = thickness of plate in sixteenths of an inch.

$$\text{Then pitch in inches} = \sqrt{\frac{80 \times (t + 1)^2}{\text{pressure}}} + 6.$$

Pressure on Stays.

Let D = diameter of stay.
P = pitch of stays.
9000 = lbs. for steel.

$$\text{Then safe pressure} = \frac{D^2 \times \cdot 7854 \times 9000}{P \times P} \text{ lbs. per sq. inch.}$$

Diameter of Stays.

Let S = surface, or pitch of stays squared.
9000 = lbs. for steel.

$$\text{Then diameter of stay} = \sqrt{\frac{\text{pressure} \times S}{9000 \times \cdot 7854}}.$$

Joints.

In nearly every type of boiler it is necessary to have flanged joints. The principal methods of connecting the shell to the end plates are: riveting to an angle iron ring, and flanging the end plates.

The most approved method is flanging the end plate; this is done, as shown in Fig. 57, where the end plate is flanged outwards,

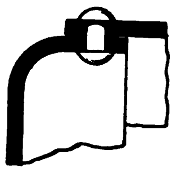


FIG. 57.—End plate flanged outwards.

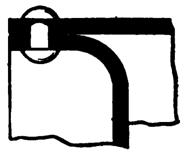


FIG. 58.—End plate flanged inwards.

or as in Fig. 58, where the flange is inwards. This method of attaching the end plate to the shell allows for ample expansion and makes a very flexible joint. The radius of the flange curve is about four times the thickness of the plate.

Two other methods are shown in Figs. 59 and 60. In Fig. 59, the shell and end plate are riveted to an angle iron ring placed inside

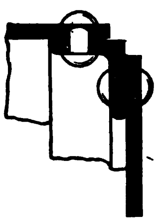


FIG. 59.—Inner angle iron ring.

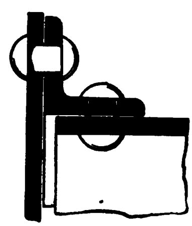


FIG. 60.—Outer angle iron ring.

the plates, and in Fig. 60 the ring is outside the plate. The two latter methods are not generally adopted, except for very small boilers.

In shell construction, the lap joint is used for circumferential seams, and the single and double butt-strap joint for longitudinal seams. When three or more plates meet, as they do when shell rings are riveted, then it is necessary to thin out some of the plates at the joints. This arrangement is shown in Fig. 61.

Welded Joints.—Welded joints are stronger than riveted ones and are nearer the strength of the plate itself, and at the same time the plate is not strained as it is in a lap joint. Modern methods of boiler manufacture give good sound reliable welds.

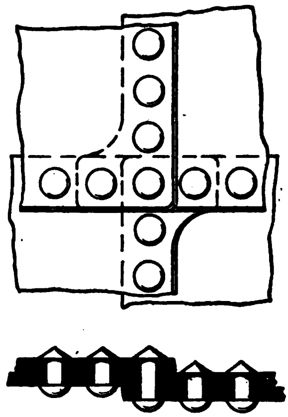


Fig. 61.—Method of joining three plates.

Connecting Parallel Plates.

When parallel plates have to be connected together, as in the case of vertical boilers, several methods can be adopted. Fig. 62 shows the use of a solid ring, Fig. 63 a channel iron, and Fig. 63A shows a method of setting the inner plate, which provides a good

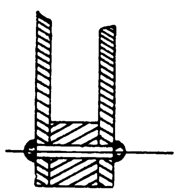


Fig. 62.—Connecting plates with a solid ring.

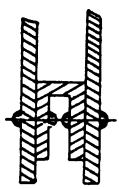


Fig. 63.—Connecting plates with channel iron.

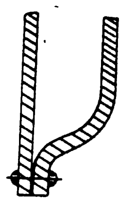


Fig. 63A.—Method of connecting plates.

flexible joint, the only disadvantage being that the space between the plates allows scale and sediment to settle, and this is rather difficult to dislodge.

Manholes and Mudholes.

Manhole and mudhole doors are usually constructed from mild steel hydraulically pressed into shape.

6

The type generally adopted for marine work and for the bottom doors of Lancashire type boilers are oval in shape, as shown in Fig. 64; this type of manhole door has the advantage of taking up very

FIG. 64.—Manhole door for Lancashire boiler.

little room and of not projecting to any great extent from the boiler plates.

In making a joint with this type of cover, a piece of jointing material is cut in the form of a ring, and placed in the recess turned in the flange of the cover. The recess fits the projecting flange fitting, which is shown in Fig. 65. The studs for holding the door in position are screwed into the cover and riveted over at the back.

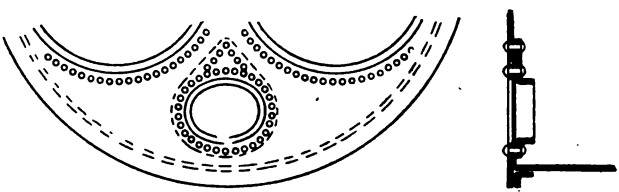


FIG. 65.—Oval manhole for front end plate.

For boilers of from 6 feet 6 inches to 8 feet in diameter, the size of the manhole is usually 15 inches by 11 inches, and for boilers above that diameter, the size is 16 inches by 12 inches.

The top manhole of Lancashire type boilers of large size generally take the form of a raised mouthpiece fitting of weldless steel, riveted

to the boiler shell and supported by a ring, as shown in Fig. 66. The manhole cover has a faced flange, and the joint is made either with a special jointing material, or with red lead, suitable bolts being provided for the purpose.

Manholes in boiler shells should be placed as far as possible from seams, the most suitable position being the middle of a plate. A strengthening ring is fitted in nearly all cases, and secured to the shell by means of a double row of rivets which pass through the manhole flange, and a further row of rivets which pass through the strengthening ring and the shell plate.

Mudholes.—Mudholes and tube sightholes are provided for in vertical boilers. It is usual to fit at least three mudholes round the base for cleaning purposes, and one sighthole opposite the end of each water tube.

Mudhole covers are made from pressed steel, the faces of the

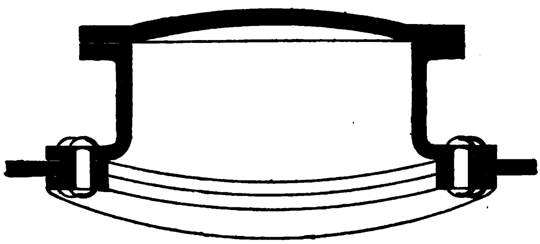


FIG. 66.—Circular manhole with compensating ring.

mouthpiece and the flange of the door being machined with not more than $\frac{1}{16}$ inch clearance between the spigot and the inside of the mouthpiece fitting; a suitable dog and riveted stud is fitted for tightening up the joint.

Caulking and Fullering.

In order to prevent the leakage of steam or water between the seams of riveted plates, it is usual to caulk or fuller the edge of one of the plates. The object desired in both caulking and fullering is the same, and that is to close in the edge of the plate on to the seam of the adjacent one in such a manner as not to injure or indent the adjacent plate, and at the same time to make a steam and water-tight joint.

Fullering and caulking are usually carried out with pneumatic tools. In fullering, a tool is used of the same thickness as the plate, as shown in Fig. 67. The tendency of the fullering tool is to force

the whole of the edge of the plate into very close contact with the adjacent plate.

For caulking, a thinner tool is used with a rounded edge (Fig. 68), and by this means a smaller amount of metal is forced into contact with the adjacent plate.

Fullering is preferred to caulking, as there is less possibility of

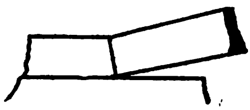


FIG. 67.—Fullering.

FIG. 68.—Caulking.

indentations being made in the adjacent plate owing to the wider surface of metal acted upon.

Well riveted and carefully fitted plates require very little, if any, caulking or fullering, but whether this is done or not, the edges of all plates should be accurately machined.

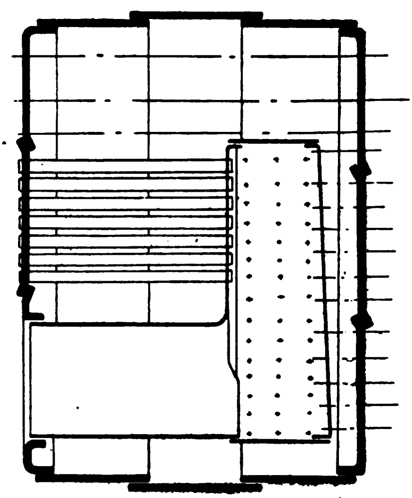


FIG. 69.—Section of marine type boiler.

Boiler Design.

The general arrangement of shell and combustion chamber plates of a marine boiler are shown in Fig. 69. The following give the thickness of plates and other particulars of a modern Scotch marine boiler :—

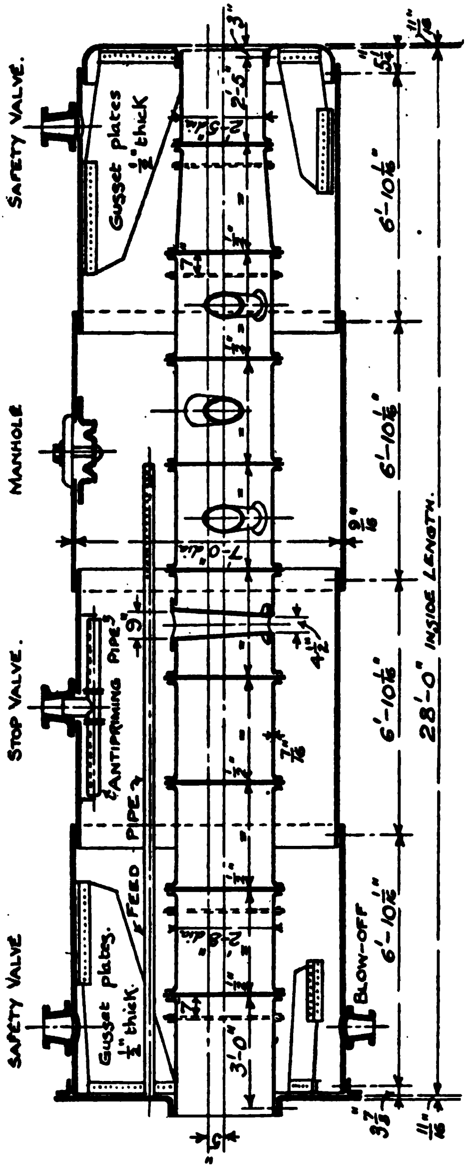


FIG. 70.—Section of Lancashire boiler.

Particulars of Scotch Marine Boiler.

Working pressure	200 lbs.
Shell diameter	14 ft. 3 ins.
„ length	19 ft. 6 ins.
„ thickness	$1\frac{1}{8}$ ins.
Number of furnaces	6
Diameter of furnace	3 ft. 6 ins.
Thickness of furnace	$\frac{5}{8}$ ins.
Number of combustion chambers	3
„ of tubes	730
Diameter of tubes	$2\frac{1}{2}$ ins.
Length of tubes	7 ft. $7\frac{1}{2}$ ins.
Surface of tubes	4575 sq. ft.
Weight of boiler	68·5 tons
„ of water in boiler	40·0 tons.

Lancashire Boiler.

The general arrangement of plates and mountings of a modern type of Lancashire boiler will be seen in Fig. 70. The various thicknesses of plates are clearly shown. This boiler is capable of evaporating about 4500 lbs. of water per hour; its grate area is 35 sq. feet, and heating surface 780 sq. feet, the length of the boiler being 28 feet and the diameter 7 feet. Boilers of this type up to 7 ft. 6 ins. in diameter are generally constructed with an angle ring between the front plate and shell, and when above that diameter the shell plate is usually flanged.

CHAPTER VI.

FLUE, SMOKE TUBE, AND MIXED TYPES OF HORIZONTAL BOILER.

The Lancashire and Cornish Boiler.

THE Lancashire boiler is undoubtedly the most popular boiler for factory work in the United Kingdom. The success of any steam installation is dependent to a large extent upon the efficiency and economy with which the steam generator can be worked under everyday conditions, because an uneconomical boiler will considerably neutralise any advantages of a modern high class engine. No single type of boiler can be said to be the best for all conditions of working, and many factors must first be considered before a particular type of boiler is decided upon.

The chief considerations are: the fuel with its cost, calorific value, and class; and the water, its purity and possible temperature. The quality of the water supply is of particular importance, as this will often decide the type of boiler to be adopted. Should the water contain a considerable amount of scale-forming salts, then it must either be softened or a type of boiler selected which will allow of easy access to the inside, so that scaling may be carried out in an effective manner.

The Lancashire and Cornish boiler are both of well-tried design, possessing simplicity, are easy of access, and seldom give serious trouble. The former was introduced by Fairburn in Lancashire, and the latter by Trevithick for power production in the tin mines of Cornwall. Both types of boilers are particularly safe, and fairly economical in working; their large holding capacity and steady steaming combine to produce a good reserve of power, and it is possible to give a large grate area to allow for burning an inferior quality of fuel.

Lancashire boilers are constructed in sizes ranging from 6 feet diameter and 19 feet long, to 9 feet 6 inches in diameter and 32 feet long. Cornish boilers are made in all sizes up to about 6 feet 6 inches diameter and 26 feet long.

Fig. 71 illustrates, in section and elevation, a Lancashire boiler with its setting, by Messrs. Marshall & Sons, Gainsborough. This

represents their standard type of boiler up to 7 feet in diameter; above that size both end plates are flanged. The shell plates are made from Siemens-Martin mild steel for working at 100, 125, or 150 lbs.

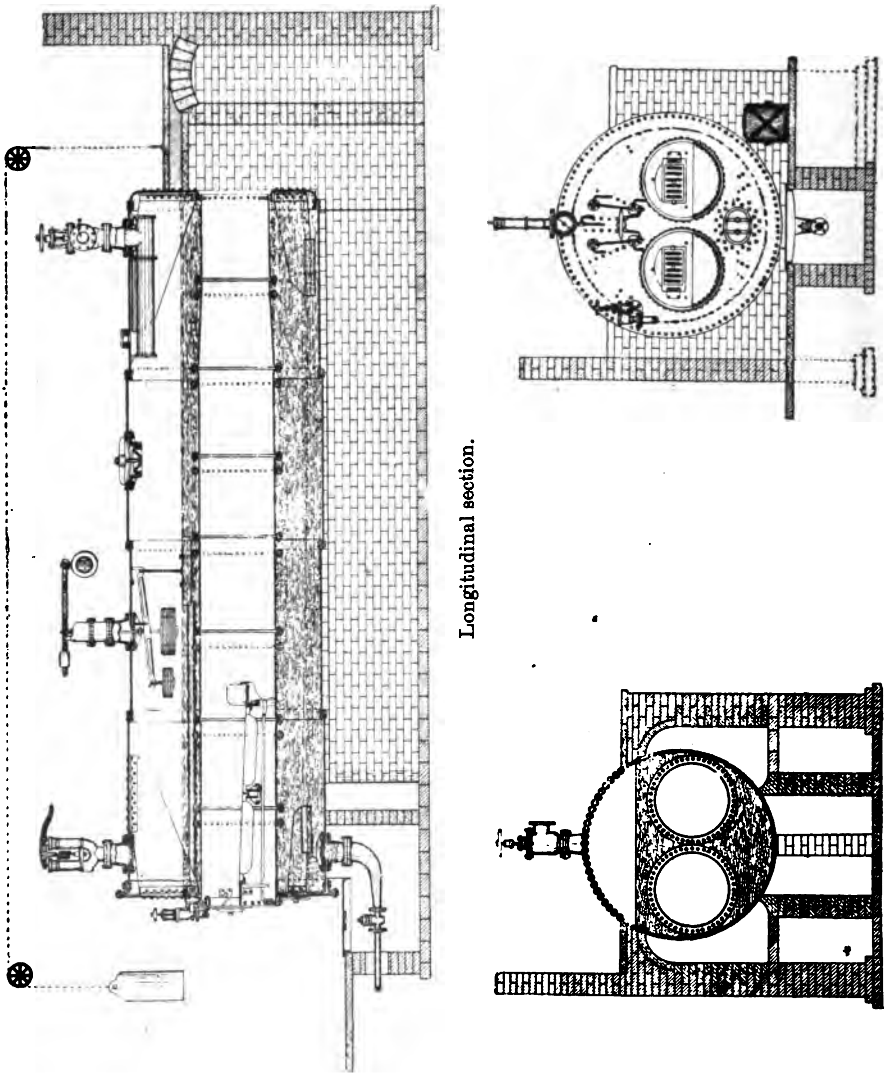


FIG. 71.—Lancashire boiler and setting by Marshall.

per sq. inch. The internal flues are also of steel, and are strengthened by flanged seams.

The following table gives the various sizes of Lancashire boilers, and represents the practice generally adopted by British manufacturers:—

TABLE 8.—STANDARD SIZE LANCASHIRE BOILERS.

Size. Length × Diam.	Heating Surface.	Normal Grate Area.	Outside Diam. of Flues.	Steam Evaporated per Hour, Lbs.			Approximate Net Weight.	
				Coal Burnt per Sq. Ft. Grate per Hour.			Working Pressure.	
				20 Lbs.	25 Lbs.	30 Lbs.	120 Lbs.	160 Lbs.
Ft. Ft. Ins.	Sq. Ft.	Sq. Ft.	Ft. Ins.	Lbs.	Lbs.	Lbs.	Tons.	Tons.
14 × 5 6	290	14·5	2 1	2300	2900	3500	6·5	7·5
16 × 5 6	340	16	2 1	2500	3200	3800	7	8·3
18 × 5 6	390	17·2	2 1	2700	3400	4100	7·5	8·8
16 × 6 0	360	19·5	2 4	3100	3900	4700	7·5	8·8
18 × 6 0	410	21	2 4	3400	4200	5000	8·3	9·8
20 × 6 0	460	22·5	2 4	3600	4500	5400	9	10·8
22 × 6 0	510	22·5	2 4	3600	4500	5400	9·8	11·3
20 × 6 6	520	23·2	2 7	3700	4600	5600	9·8	11·8
22 × 6 6	570	25	2 7	4000	5000	6000	10·3	12·3
24 × 6 6	620	27·5	2 7	4400	5500	6600	11	13·5
26 × 6 6	670	30	2 7	4800	6000	7200	12	14·3
24 × 7 0	680	29·7	2 9	4800	6000	7200	13·3	15·5
26 × 7 0	740	32	2 9	5100	6400	7700	14·3	17·3
28 × 7 0	800	32	2 9	5100	6400	7700	15·5	18
30 × 7 0	860	32	2 9	5100	6400	7700	16·5	19
28 × 7 6	870	35	3 0	5600	7000	8400	16·3	20
30 × 7 6	930	35	3 0	5600	7000	8400	17·3	21·3
28 × 8 0	930	38	3 3	6100	7600	9100	18	23·3
30 × 8 0	1000	38	3 3	6100	7600	9100	19	24
30 × 8 6	1050	40	3 5	6400	8000	9600	21·5	26·3
30 × 9 0	1120	43	3 8	6900	8600	10,300	23·5	29·5

BASIS.—8 lbs. of water evaporated per lb. of coal. Boiler supplied with hot feed water.

Another first-class example of a modern Lancashire boiler is that shown in Plate I.; this boiler is by Messrs. Galloway, Manchester, and is designed for a working pressure of 200 lbs. per sq. inch. Its general construction is clearly shown in the plate, the gusset stays for the back end plate being shown in Fig. 72.

Another make of Lancashire boiler is illustrated in Fig. 73, and shown in section with the internal construction at Fig. 74. This

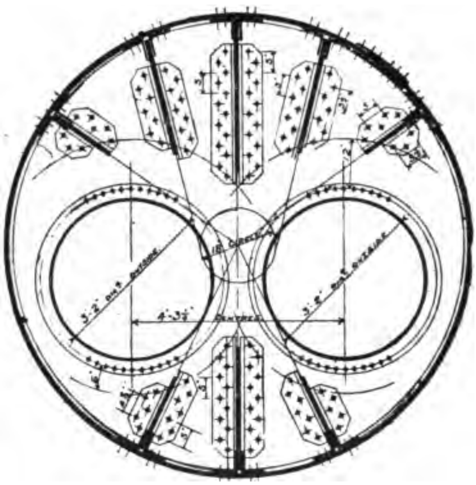


FIG. 72.—Method of staying back end of a Lancashire type boiler.

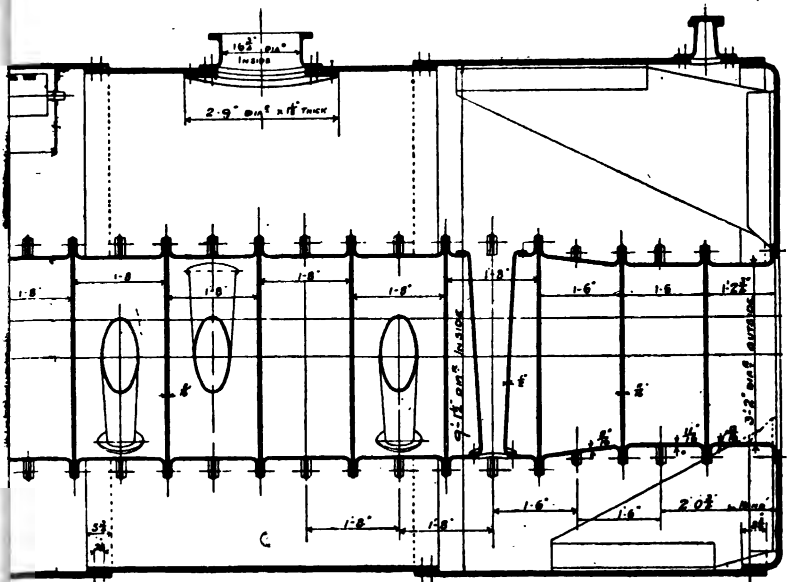
boiler is made by Messrs. Holdsworth & Sons of Bradford, and the details of it are clearly shown in the illustration.

The standard sizes and approximate evaporative power and weights of this boiler are:—

Shell diameter	6′ 6″	7′ 0″	7′ 6″	8′ 0″	8′ 6″	9′ 0″
„ length	24′ 0″	28′ 0″	28′ 0″	30′ 0″	30′ 0″	30′ 0″
Grate area, sq. feet . . .	25	30	36	39	42	45
Approx. evaporation per hour easy steaming, in lbs. . . .	3750	4800	5760	6630	7560	7920
Approx. weight in cwts. for 150 lbs. working pressure . . .	262	326	358	436	490	564
Approx. weight in cwts. of fittings and mountings for 150 lbs. working pressure . . .	60	67	72	78	85	93

The Cornish Boiler.

When a boiler of smaller evaporative power than can be economically obtained from a Lancashire type boiler is wanted, the



[*To face page* 90.

Cornish will often be found suitable. The design resembles the Lancashire, and consists of a cylindrical shell, provided with flat end plates, and one furnace tube.

Cornish boilers are usually constructed between the limits of

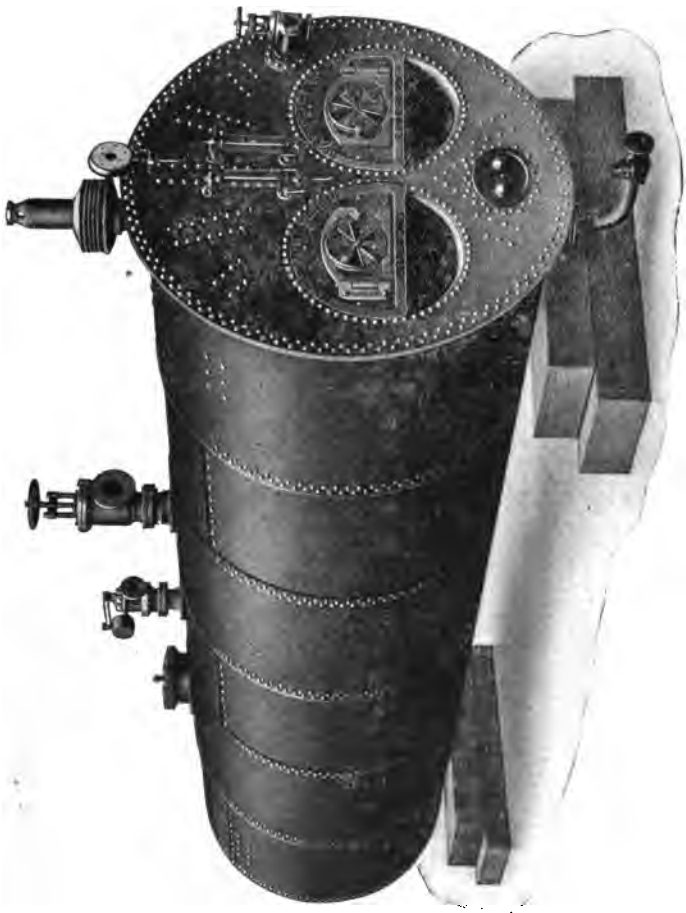


FIG. 73.—Lancashire boiler by Messrs. Holdsworth & Sons.

4 feet × 12 feet and 6 feet 6 inches × 24 feet, and are used where fuel can be obtained at moderate cost, and the necessary brickwork setting and chimney stack can be easily provided. They are constructed to withstand pressures up to 150 lbs. per sq. inch, and are sometimes fitted with cross-tubes in the flues.

Fig. 75 illustrates a Cornish boiler in section, with its setting.

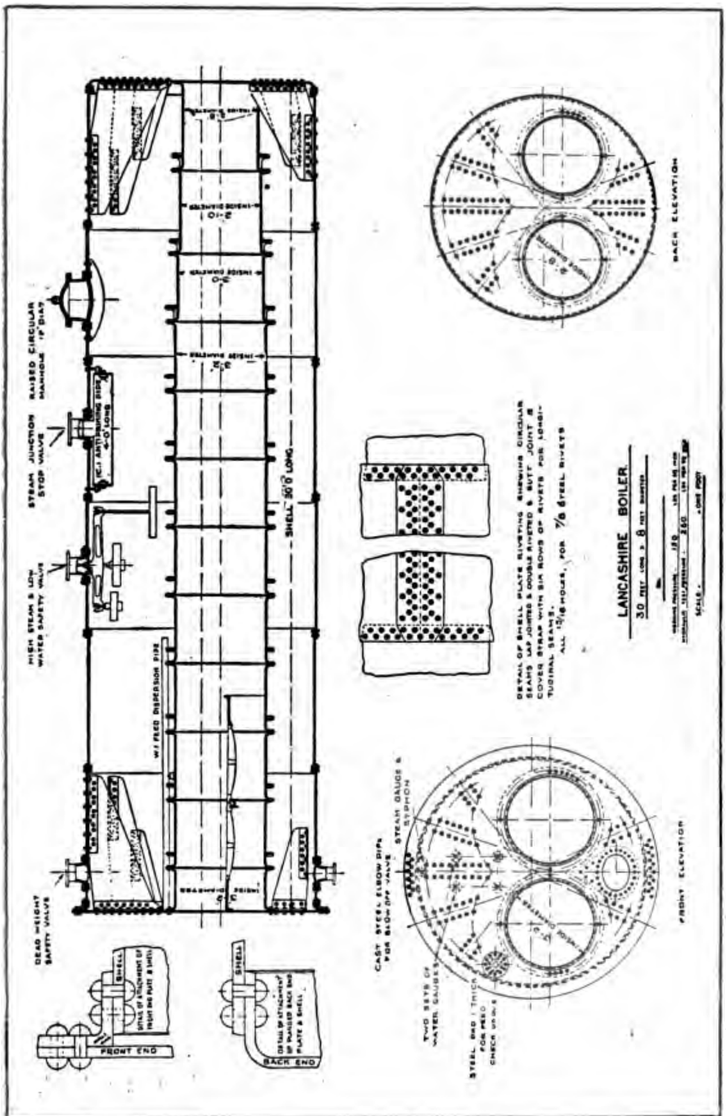
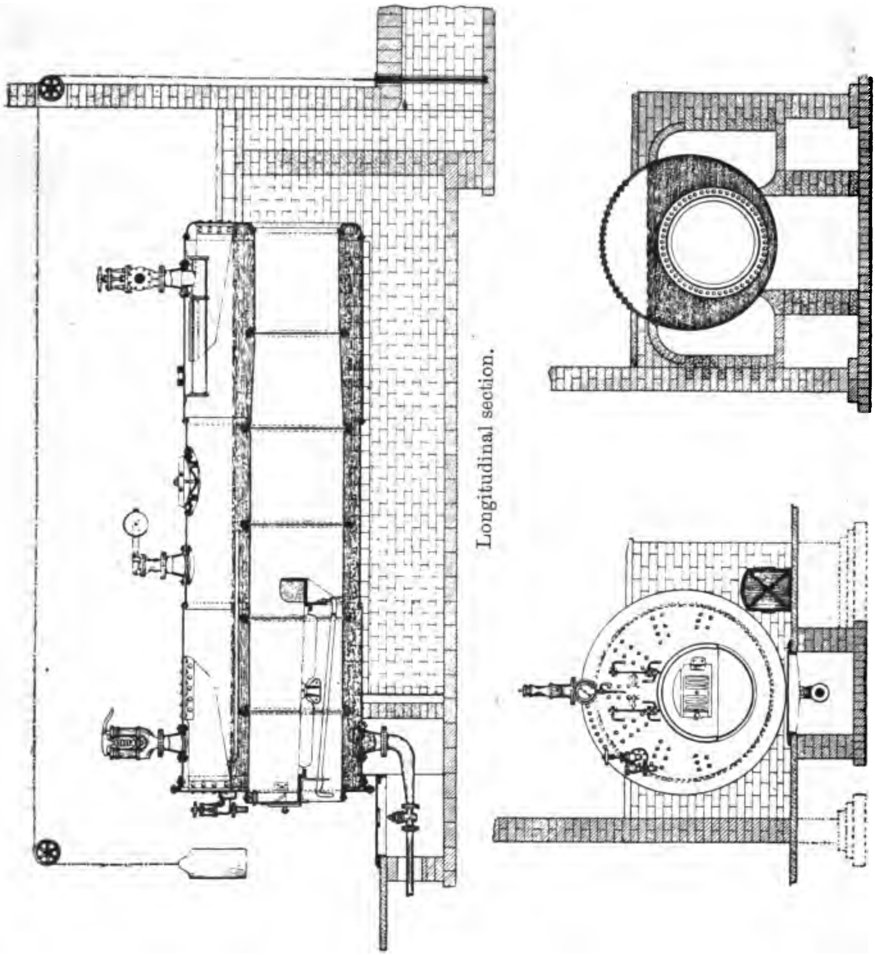


FIG. 74.—Sectional view with details of Lancashire boiler.

TABLE 9.—STANDARD SIZES OF CORNISH BOILERS.

Diameter of shell	4′ 0″	4′ 6″	4′ 6″	5′ 0″	5′ 0″	5′ 0″	5′ 6″	5′ 6″	5′ 6″	6′ 0″	6′ 0″	6′ 6″	6′ 6″
Length of shell	12′ 0″	12′ 0″	14′ 0″	16′ 0″	18′ 0″	20′ 0″	16′ 0″	18′ 0″	20′ 0″	18′ 0″	20′ 0″	20′ 0″	24′ 0″
Outside diameter of flue . .	2′ 3″	2′ 6″	2′ 6″	2′ 9″	2′ 9″	2′ 9″	3′ 0″	3′ 0″	3′ 0″	3′ 8″	3′ 3″	3′ 6″	3′ 6″
Square feet of heating surface .	9	10	10	13·75	13·75	13·75	15	15	15	16·25	16·25	18	21
,, ,, of grate area . .	192	220	250	326	354	408	342	382	428	432	484	530	552
Maximum evaporation, lbs. of water per hour	960	1100	1270	1630	1770	2040	1710	1910	2140	2160	2420	2645	3120

A modern type of high-pressure Cornish boiler is shown in Fig. 76, the same boiler is seen in longitudinal section at Fig. 77. This boiler is made by Messrs. Holdsworth & Sons, Bradford, and is 6 feet in diameter and 20 feet long. The shell is of Siemens-Martin mild



Cross section. Front elevation.

FIG. 75.—Cornish boiler and setting.

steel, with a safety factor of five. The front end is attached to the shell by a solid welded steel angle ring. All the plate edges are planed and fullered, all rivet holes drilled, and the riveting done by hydraulic machines.

The standard sizes and approximate evaporating power of these boilers are :—

Evaporative Power of Cornish Boilers.

Shell diameter	4′ 6″	5′ 0″	5′ 6″	6′ 0″	7′ 0″
,, length	15′ 0″	18′ 0″	19′ 0″	20′ 0″	24′ 0″
Grate area, sq. feet	9	12·5	16·5	18	21
Approx. evaporation per hour easy steaming, in lbs.	1250	1750	2310	2520	3170
Approx. weight in cwts. for 150 lbs. working pressure	89	121	145	182	223
Approx. weight of fittings and mountings for 150 lbs. working pressure . .	13	14	17	18	21

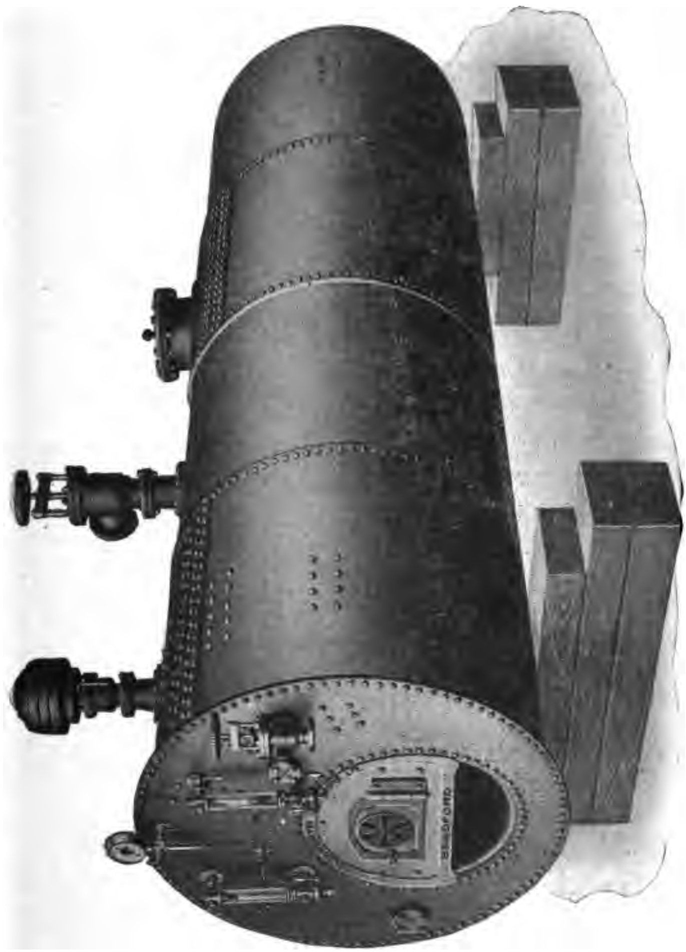


FIG. 76.—High-pressure Cornish boiler.

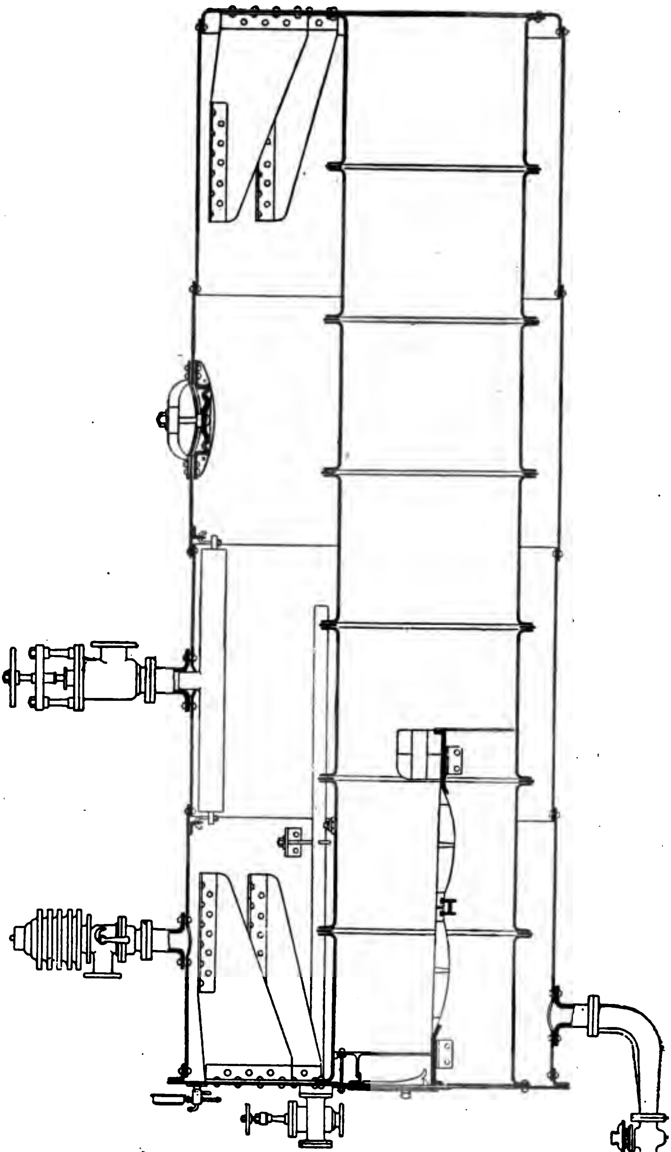


Fig. 77.—Longitudinal section of a Cornish boiler,

The Yorkshire Boiler.

The Yorkshire boiler was designed and patented by Mr. W. H. Casmey of Wakefield, in 1906, and is a type of steam generator, in some respects similar to the Lancashire boiler, though differing in some important details, and Messrs. Holdsworth & Sons, Bradford, are the sole makers.

The Yorkshire boiler is built to the same range of diameters as the Lancashire boiler, but its maximum length is only 24 feet, the minimum length 12 feet, whereas the standard Lancashire is 30 feet; notwithstanding this big difference in heating surface, the evaporating power of the Yorkshire is claimed to be in excess of that secured from the longer boiler. The essential difference between the two boilers is in the design of the furnace flues.

In the Lancashire, the flues are practically parallel from the front to within 5 or 6 feet of the back, from which point they taper to the end of the boiler, the generally accepted reason for such taper being that it allows the boiler attendants to pass down from the upper side to the lower side of the tubes for cleaning, inspection, etc.

As the contraction or taper of the flues reduces the sectional area by 30 per cent. at the rear, it of course increases the weight of water at the rear of the boiler proportionally, thus giving the biggest weight of water where the heating surface is smallest and the temperature of the gases the lowest, conditions which are far from scientific, and which may be the cause of loss in efficiency.

The furnace flues of the Yorkshire boiler are gradually enlarged from front to back, and are also arranged in a slightly inclined position the centre line being a few inches higher at the back than at the front end.

The object of enlarging the furnace tubes are :—

A. To make the boiler front and flues more elastic, thus removing some of the dangers of grooving.

B. To enable inspection and cleaning of the front end of the furnace tubes where the chief work of a tank boiler is done.

C. As the gases leave the fires and pass along the gradually increasing sectional area of the flue, their density is reduced, and the atmospheric pressure endeavours to balance this reduction, so that a powerful draught is produced through the fires, the increased draught giving a better combustion and therefore a higher furnace temperature.

D. The gradually increasing section of the furnace flues distributes the heat and water proportionally throughout the boiler. The

smallest heating surface, maximum heat transmission, and maximum head of water are at the front of the boiler, the largest heating surface, lowest gas temperature, and minimum head of water are at the rear.

A section through a Yorkshire boiler, 9 feet diameter and 24 feet long, together with front and back end views, with details of plate connections, will be seen in Fig. 78; a front elevation of five boilers 9 feet 4 inches diameter and 24 feet long is shown at Fig. 79.

The furnaces at the front end are designed so that they may be withdrawn through the holes in the front end plate. The extreme ends are seen to be joggled out to a diameter greater than that of the flanges at the back ends, the end plates being flanged outwards at the holes to suit.

The Yorkshire boiler has a fire-grate area considerably less than that of a Lancashire boiler of the same diameter shell, and yet the makers claim that the latter boiler reaps no advantage for the following reason: the tubes of the Lancashire boiler are tapered down at the back end to such an extent that the effective area for the passage of the gases at the back end is only about two-thirds of that at the front end. This reduction of area is believed to impede the passage of the hot gases and reduce the efficiency of the boiler.

A Yorkshire type boiler 9 feet diameter has a grate area of 39 sq. feet, and the sectional area of the flue tube outlet at the downtake is 21 sq. feet. The corresponding figures for a Lancashire boiler of the same size are 44 and 15·6 sq. feet respectively. The ratio of grate area to the outlet area is thus 1·8 to 1 for the former, and 2·8 to 1 for the latter. The former will, however, burn as much fuel per sq. foot of fire-grate, with dampers one-third down, as the latter will with dampers full open. In other words, the Yorkshire boiler with 30 sq. feet of grate area will do as much work as a Lancashire boiler with 44 sq. feet, the draught in the two cases being the same.

The following table gives the standard sizes and approximate evaporative power of this type of boiler:—

TABLE 10.—STANDARD SIZES OF YORKSHIRE BOILERS.

Shell diameters	6′ 0″	6′ 6″	7′ 0″	7′ 6″	7′ 6″	8′ 0″	8′ 0″	8′ 6″	8′ 6″	9′ 0″	9′ 4″
„ lengths	17′ 0″	17′ 0″	20′ 0″	20′ 0″	24′ 0″	20′ 0″	24′ 0″	24′ 0″	24′ 0″	24′ 0″	24′ 0″
Grate area, sq. feet	14	20	23	25	30	30·25	33	33	36	39	42
Approx. evaporation per hour	2898	3750	4916	5790	6624	6780	7797	7589	8730	9459	11000

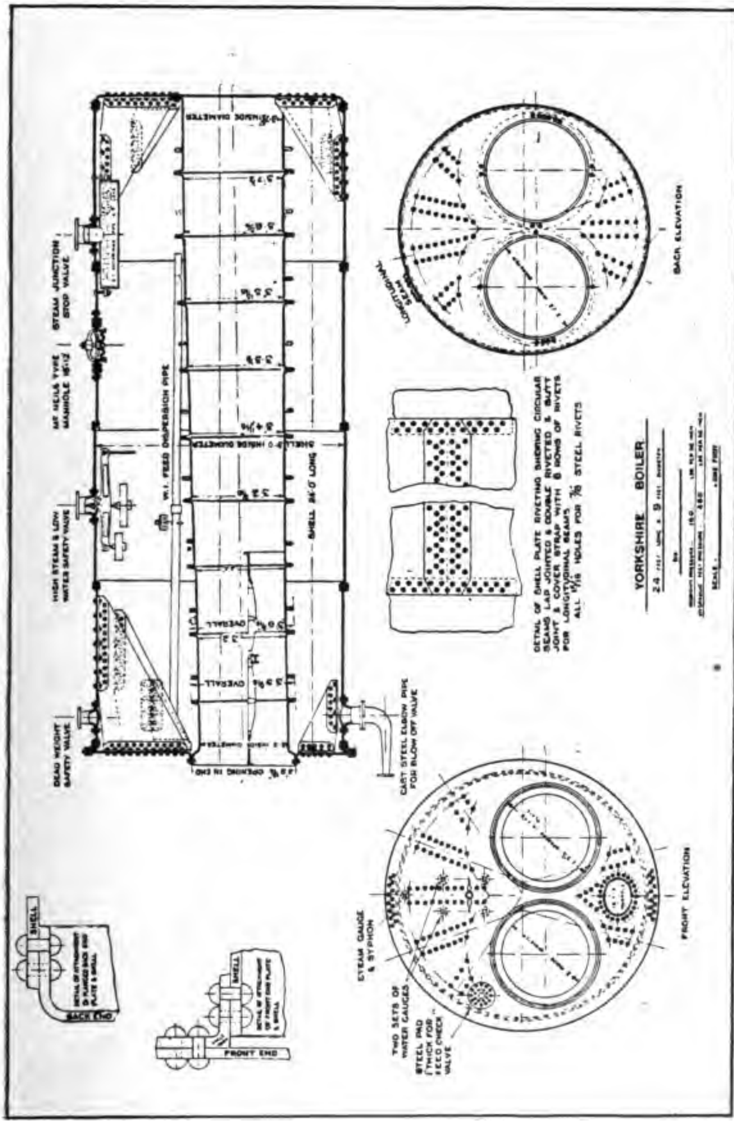


FIG. 78.—Sectional view with details of Yorkshire boiler.

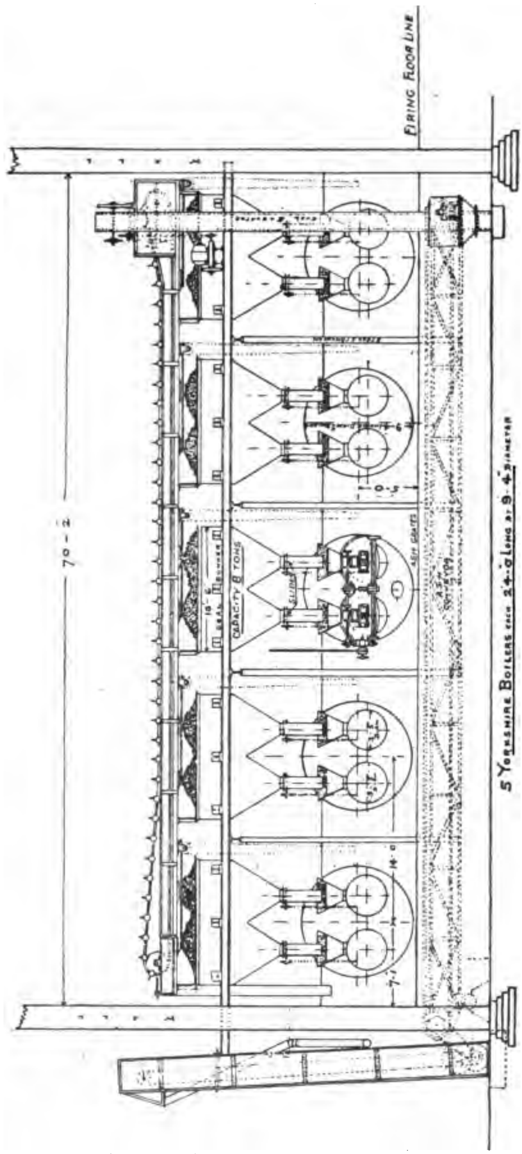


FIG. 79.—Front elevation of five Yorkshire boilers.

Evaporative Test of Yorkshire Boilers.

The following figures give the result of an evaporative test of four 9 feet 4 inches × 24 feet boilers :—

Date of test	21st October, 1917.
Duration of test	8 hours.
Working pressure	175 lbs. per sq. inch.
Heating surface per boiler	925 sq. feet.
Grate area	42 „ „
Feed water:—	
Temperature of water in pump tank	59·5° Fah.
„ „ „ leaving economiser	282° „
Water evaporated per boiler per hour	10,718 lbs.
Coal and ashes:—	
Calorific value of coal	13,680 B.T.U.'s.
Weight of coal used	51,296 lbs.
Percentage of ash and clinker	17·3
Moisture in fuel	1·26 per cent.
Weight of coal consumed per boiler per hour	1522 lbs.
„ „ dry coal used per boiler per hour	1306 „
Gases:—	
Temperature in side flues, average	696·5° Fah.
„ at base of chimney	352° „
Draught at base of chimney	1 in W.G.
„ in side flues	·5 „ „
Superheat, average of 76 readings	634° Fah.
Results:—	
Equivalent evaporation per boiler per hour "from and at 212°"	15,244 lbs.
Equivalent evaporation per lb. of coal burned "from and at 212°"	10·01 „
Equivalent evaporation per lb. of dry fuel "from and at 212°"	11·67 „
Efficiency	78 per cent.

The Galloway Boiler.

The Galloway boiler, as shown in section and plan in Figs. 80 and 81, is the speciality of Messrs. Galloway, Manchester. The flues of the boiler are two in number, and are riveted to a common oval-

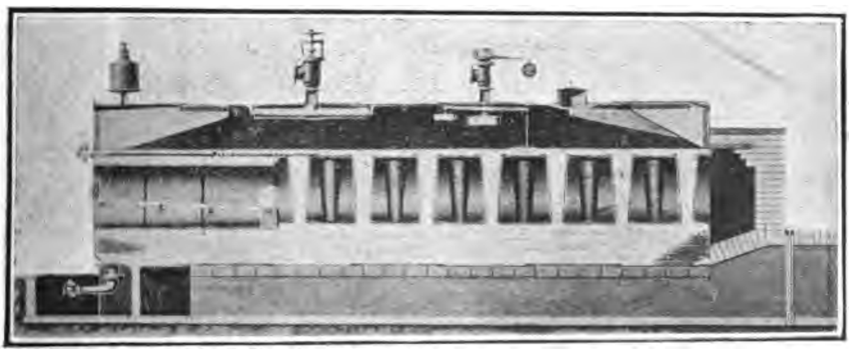


FIG. 80.—Longitudinal section of Galloway boiler, showing brickwork setting.

shaped tube, at a position just behind the furnace bridge. The oval tube is continued to the back end plate, and is fitted with a number of conical Galloway tubes, the number being determined by the

size of the boiler. The introduction of these conical tubes is claimed to give an increased evaporation; whether this is so or not is a question which ought to be definitely decided, but it is a fact that a

FIG. 81.—Plan of Galloway boiler.

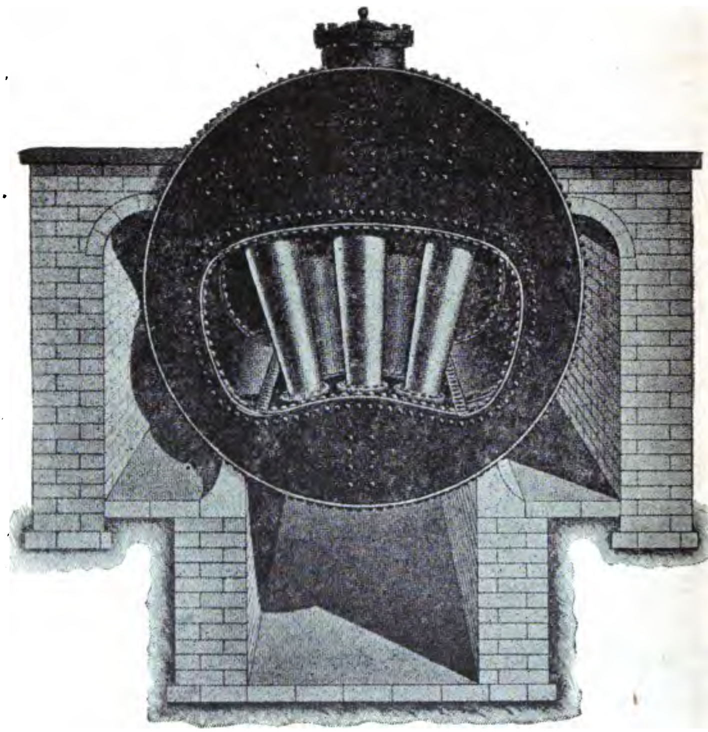


FIG. 82.—Rear view of Galloway boiler.

number of manufacturers who formerly used these tubes have now discarded them. The opponents of the Galloway tube say that they cause sorting up, and break the gas flames, while Messrs. Galloway

point to tests which show an evaporation of 12·8 lbs. of water from and at 212° Fah. per lb. of Welsh coal. A back view showing the Galloway tubes and brickwork setting is illustrated in Fig. 82.

The usual method of arranging the brickwork flues of these boilers is to allow the products of combustion escaping from the furnace

FIG. 83.—Circulation in Galloway tubes.

flues to pass along the sides of the boiler, and then down and along the bottom of the boiler to the shaft. The water circulation taking place in the Galloway tubes will be seen in Fig. 83.

Table 11 (on next page) gives the standard sizes and evaporative power of the Galloway boiler.

Dish-ended Boilers.

A modern type of dish-ended boiler with corrugated flues, by Messrs. Thompson, Wolverhampton, is illustrated in Plate II. The boiler is constructed for a working pressure of 230 lbs. per sq. inch, and the following advantages are claimed: no gusset stays are required, as the end plates are increased in thickness to give the necessary factor of safety required by the boiler insurance companies; all the rivets connecting the end plates to the shell and flues are subject to shearing instead of tensile strain; the absence of stays allows of quicker and easier boiler scaling; the corrugations in the flues baffle the flame, and cause it to impinge upon them, the full value of heat being obtained; the corrugated flues give about 15 per cent. increased heating surface.

TABLE 11.—STANDARD SIZES OF GALLOWAY BOILERS.

Size. Length × Diam.	No. of Cone Tubes.	Heating Surface.	Normal Grate Area.	Outside Diam. of Furnace.	Steam Evaporated per Hour, Lbs. Coal Burnt per Sq. Ft. Grate per Hour. 20 Lbs.	25 Lbs.	30 Lbs.
Ft. Ft. In.		Sq. Ft.	Sq. Ft.	Ft. Ins.	Lbs.	Lbs.	Lbs.
14 × 5 6	6	300	14·5	2 1	2500	3100	3700
16 × 5 6	8	350	16	2 1	2700	3400	4100
18 × 5 6	8	395	17·2	2 1	2900	3600	4400
16 × 6 0	8	395	19·5	2 4	3300	4100	5000
18 × 6 0	11	445	21	2 4	3500	4400	5300
20 × 6 0	11	495	22·5	2 4	3800	4800	5700
22 × 6 0	14	555	22·5	2 4	3800	4800	5700
20 × 6 6	15	570	23·2	2 7	3900	4900	5900
22 × 6 6	15	605	25	2 7	4200	5300	6400
24 × 6 6	18	675	27·5	2 7	4600	5800	7000
26 × 6 6	18	725	30	2 7	5100	6400	7600
24 × 7 0	18	735	29·7	2 9	5100	6400	7600
26 × 7 0	20	795	32	2 9	5400	6800	8200
28 × 7 0	20	850	32	2 9	5400	6800	8200
30 × 7 0	25	925	32	2 9	5400	6800	8200
28 × 7 6	20	925	35	3 0	5900	7400	8900
30 × 7 6	25	1000	35	3 0	5900	7400	8900
28 × 8 0	25	1070	38	3 3	6500	8100	9700
30 × 8 0	25	1120	38	3 3	6500	8100	9700
30 × 8 6	25	1220	40	3 5	6800	8500	10,200
30 × 9 0	25	1310	43	3 8	7300	9100	11,000

Basis.—8·5 lbs. of water evaporated per lb. of coal. Boiler supplied with hot feed.

Cylindrical Multitubular Boiler Externally Fired.

The type of boiler illustrated in Fig. 84 has a considerable demand in some countries, as it is capable of rapidly generating a large amount of steam for the floor space it occupies. It is economical in fuel consumption, well adapted for export, on account of its small size and weight, and the furnace is designed to burn almost any description of fuel. This type of boiler should only be used where a good feed water is obtainable, or where great care is taken to prevent any accumulation of deposit on the bottom of the boiler over the fire.

The standard sizes as made by Messrs. Marshall, Son & Co. are given in Table 12.

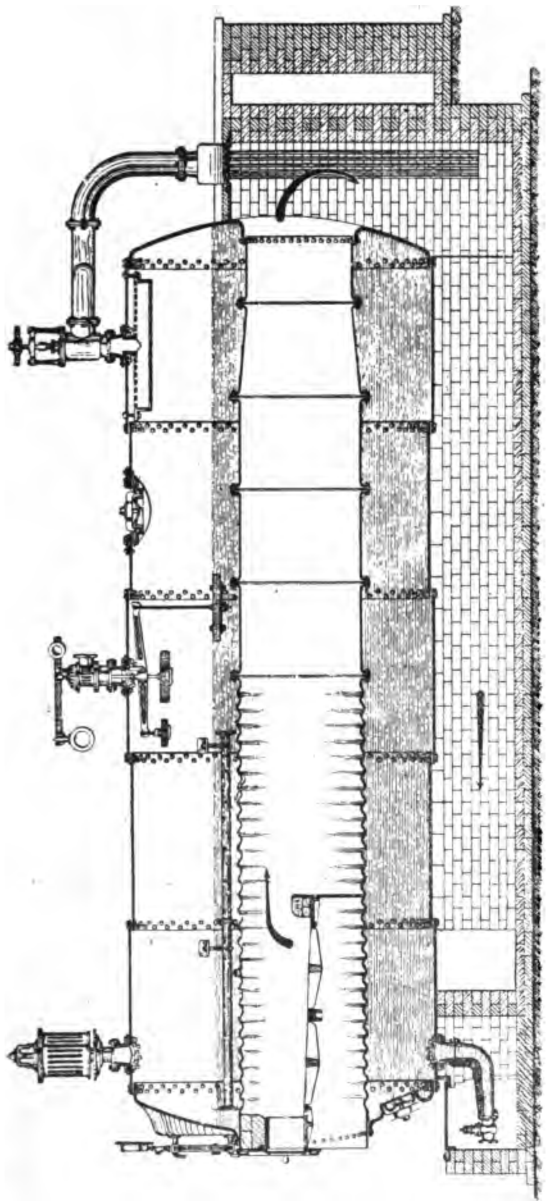


PLATE II.—Section through Thompson's dish-ended boiler with corrugated flues.

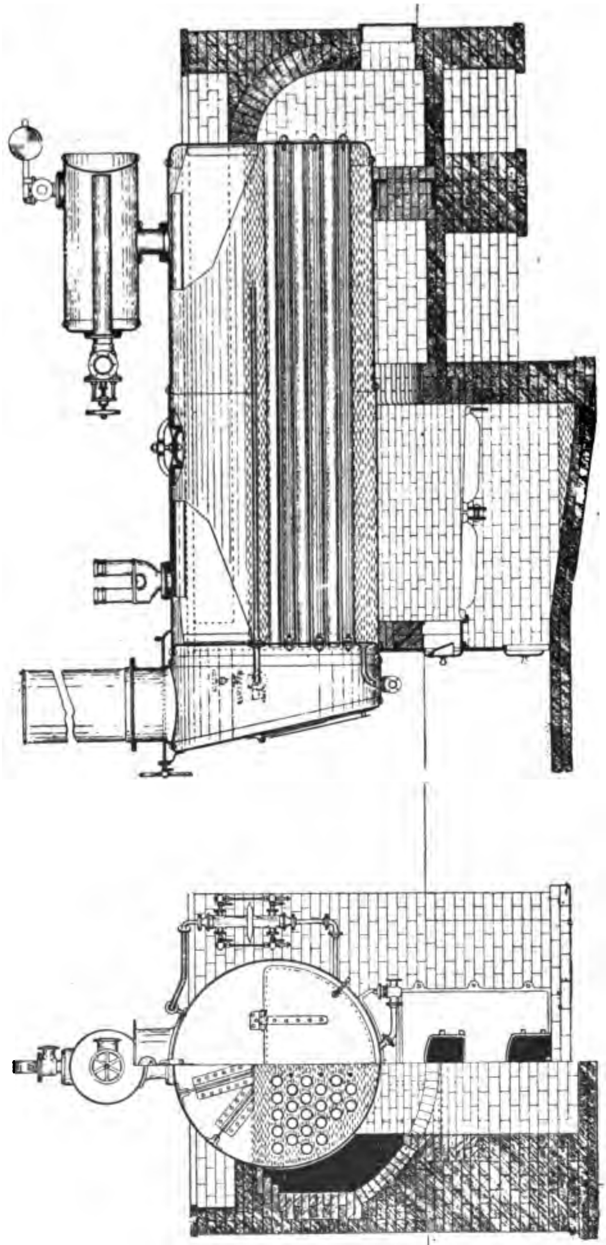


FIG. 84.—Section of an externally fired multitubular boiler.

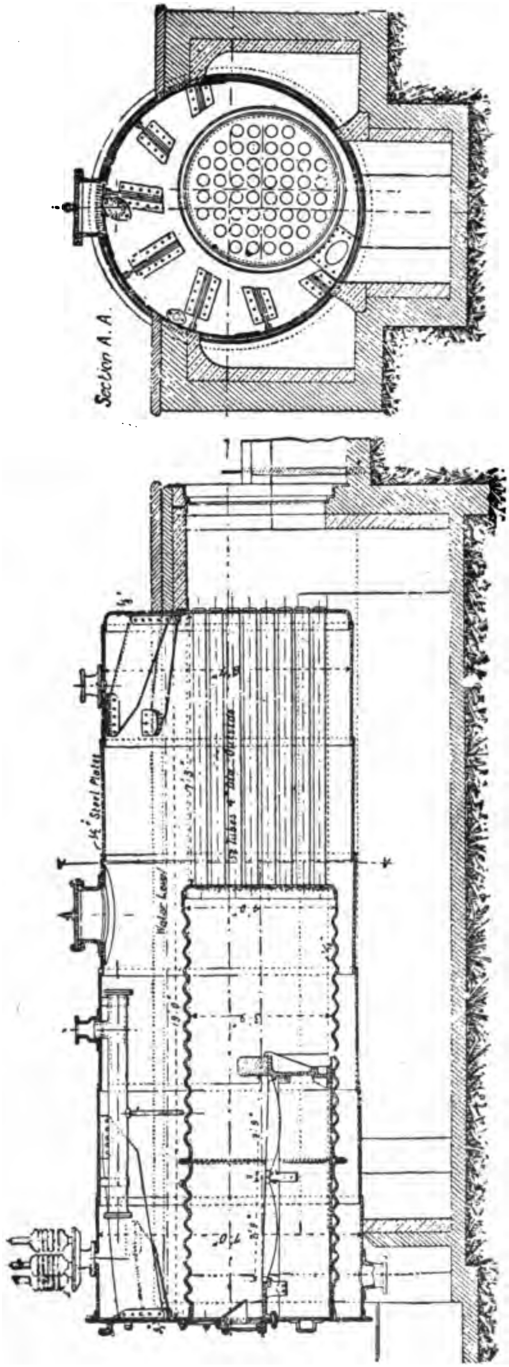


FIG. 85.—Section of a Cornish multitubular boiler.

TABLE 12.—STANDARD SIZES OF EXTERNALLY FIRED CYLINDRICAL MULTITUBULAR BOILERS.

Shell.		Tubes.		Steam Drum.		Grate Area in Square Feet.	Total Heating Surface in Square Feet.
Length.	Diameter.	No.	Diameter.	Diameter.	Length.		
Ft. In.	Ft. In.		In.	Ft. In.	Ft. In.		
9 9¾	3 0	17	3	1 6	3 0	6·6	180
13 0¾	3 0	17	3	1 6	3 0	8·4	236
12 0	3 5½	24	3	1 6	3 0	10	290
12 0	3 11	28	3	1 6	3 0	11·6	342
14 0	4 4	24	3½	1 6	3 0	13·1	395
14 0	4 8	26	3½	2 0	5 0	14·5	440
14 0	5 0	34	3½	2 0	5 0	17·5	540
14 0	5 3	43	3½	2 0	5 0	21	665
14 0	5 9	45	4	2 0	5 0	24·2	780
14 0	6 2	60	4	2 0	5 0	30	1020
14 0	6 8	77	4	2 0	5 0	38	1250

Cornish Multitubular Boiler.

This type of boiler is supplied in large numbers in connection with fixed engines, and is intended to work in localities where fuel is expensive. They are thoroughly reliable boilers when used with good soft water, and effect a saving of about 15 per cent. in fuel compared with the Cornish or Lancashire boiler. Fig. 85 shows a sectional illustration of a cylindrical multitubular boiler 19 feet long by 7 feet in diameter at the front end. The rings of the shell are arranged telescopically, so that the diameter at the rear end of the shell is 6 feet 7 inches. As will be seen from the end view, the furnace is placed on one side of the centre line, this arrangement giving readier access to the lower part of the boiler for cleaning. The boiler is set with side flues like an ordinary Lancashire boiler; the gases after leaving the tubes, pass first under the boiler, and then divide and traverse the side flues to the chimney.

The large amount of heating surface in the tubes allows of the external dimensions of these boilers being considerably less than those of the Lancashire or Cornish types of a similar evaporative capacity; they are consequently less bulky and heavy, which is often a matter of considerable importance where freight and transport have to be considered. The following are the particulars of standard sizes made by Messrs. Marshall:—

TABLE 13.—STANDARD SIZES OF CORNISH MULTITUBULAR BOILERS.

Shell.		Flue.		Tubes.		Grate Area in Square Feet.	Total Heating Surface in Square Feet.
Length.	Diameter.	Length.	Diameter.	No.	Diameter.		
Ft. In.	Ft. In.	Ft. In.	Ft. In.		In.		
8 6	3 10	5 10	2 0	16	3	4·6	121
10 0	3 10	5 9	2 0	21	3	6·6	163
10 6	4 5	6 10	2 4	29	3	8·4	204
11 6	4 5	7 0	2 4	34	3	10	243
12 6	4 9	8 0	2 7	37	3	11·6	273
13 9	5 0	9 8	2 9	32	3½	13·1	309
14 3	5 4	9 6	2 9	32	3½	14·5	356
16 3	5 9	11 0	3 0	44	3½	17·5	429
18 6	6 2	12 6	3 3	36	4	21	526
19 0	6 6	12 6	3 6	42	4	24·2	615
21 0	6 9	14 0	3 10	44	4	27·2	707
22 3	7 0	15 6	4 0	52	4	30	800
28 0	7 0	18 2	4 0	52	4	30	1143

The principal results of a seven-hour test of the boiler illustrated are:—

Combustion.

Pounds of coal burnt per sq. foot of grate surface per hour 21·5 lbs.
" " " " " " " " heating " " " 0·534 lb.

Evaporation.

Pounds of water evaporated per lb. of coal from feed temperature 9·36 lbs.
" " " " " " " " " and at 212° Fah. 10·15 "

Compound Cornish Boiler.

Fig. 86 illustrates a compound Cornish boiler constructed by the Cradley Boiler Co., Cradley Hall, Staffordshire. This type of boiler is designed for a working pressure of from 80 to 160 lbs. per sq. inch. The illustration explains the meaning of the name "Compound Cornish," for the reason that the shell is similar in every respect to the Cornish boiler, but the furnace tube terminates behind the bridge in a circular tube plate, and lap welded tubes are continued from this to the back end tube plate of the boiler, where the smoke-box is formed, and fitted with doors, for conveniently examining and cleaning the small tubes when necessary.

The gases, after leaving the tubes, are conducted by side openings in the smoke-box under the bottom or along the sides of the boiler by brick flues, in the ordinary manner, and thence to the chimney.

The brick setting is similar to that provided for the Lancashire and Cornish type boiler.

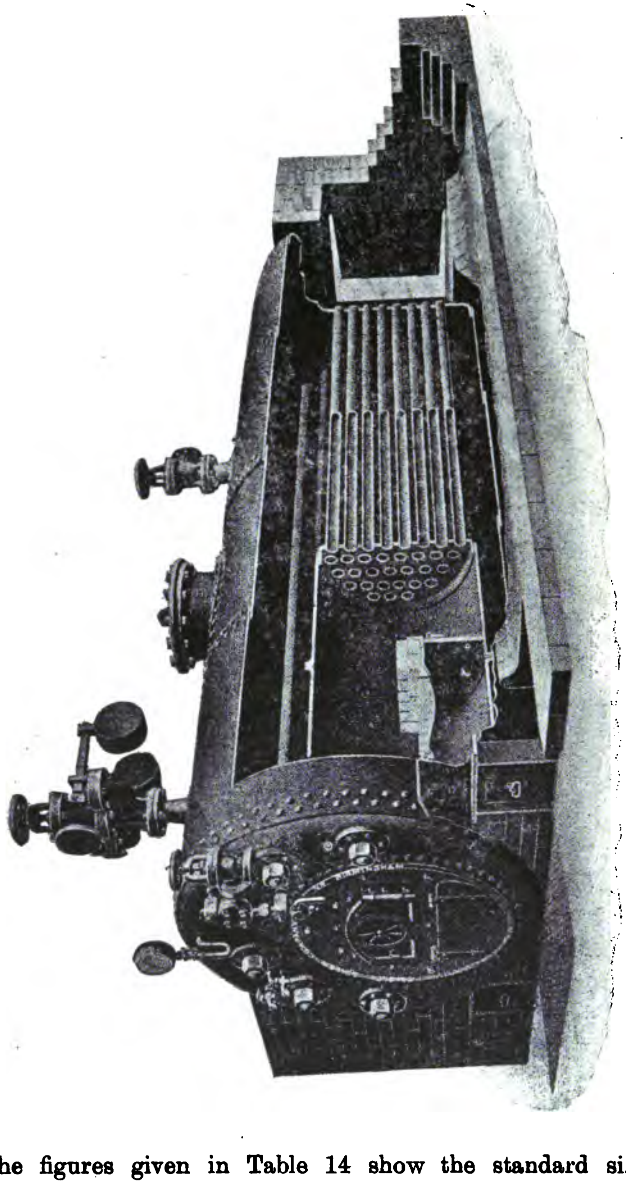


Fig. 86.—Compound Cornish boiler.

The figures given in Table 14 show the standard sizes and evaporative power of the compound Cornish boiler. The nominal horse-power, although vague and misleading, is used as a method of comparison.

TABLE 14.—STANDARD SIZES OF COMPOUND CORNISH BOILERS.

Nominal Horse-power.	10.	12.	14.	16.	18.	20.
Length of boiler	10′ 0″	12′ 0″	12′ 6″	13′ 0″	14′ 0″	14′ 0″
Diameter of boiler	4′ 6″	4′ 6″	4′ 9″	5′ 0″	5′ 0″	5′ 6″
,, ,, furnace tube	2′ 4″	2′ 4″	2′ 5″	2′ 8″	2′ 9″	3′ 0″
Number of tubes	40	40	45	55	57	64
Diameter of tubes	2½″	2½″	2½″	2½″	2½″	2½″
Grate area, sq. feet	5	6	7	8	9	10
Heating surface, sq. feet	224	276	310	360	380	415
Lbs. of water evaporated per hour	1000	1225	1375	1600	1700	1850

Nominal Horse-power.	22.	25.	30.	35.	40.
Length of boiler	15′ 0″	16′ 0″	16′ 0″	18′ 0″	20′ 0″
Diameter of boiler	5′ 6″	5′ 6″	6′ 0″	6′ 0″	6′ 0″
,, ,, furnace tube	3′ 0″	3′ 0″	3′ 3″	3′ 3″	3′ 3″
Number of tubes	66	66	70	70	70
Diameter of tubes	2½″	2½″	2½″	3″	3″
Grate area, sq. feet	11	12	15	16	17
Heating surface, sq. feet	450	475	600	660	800
Lbs. of water evaporated per hour	2000	2100	2600	2900	3200

Horizontal Multitubular Boiler.

This type of boiler has large steaming capacity, and its shipping measurements are small in comparison to its power. It can easily be constructed for high pressures, and will evaporate from 4 to 4½ lbs. of water per sq. foot of heating surface. It is extensively used on electric light installations, and, as compared with the Lancashire type boiler, requires about half the floor space only, which, in some cases, is a most important consideration, as is also the cost of brick-work, which in the case of this type of boiler is very low.

The usual arrangement in setting the boiler shown in Fig. 87 is such that the flame passes along the internal tube to a separate brick-lined combustion chamber at the back, thence through the smoke tubes, which are 3 to 4 inches in diameter, to the smoke-box at the front end, which extends across the front of the boiler. At each end of the smoke-box, openings are provided to conduct the gases round the sides and bottom, and finally to the chimney, so that the boiler is enveloped in heat, which makes it a very economical steam generator. Unlike the externally fired boiler, the bottom of the boiler is least hot, and, therefore, there is less risk of overheating this part, should there be any sediment at the bottom.

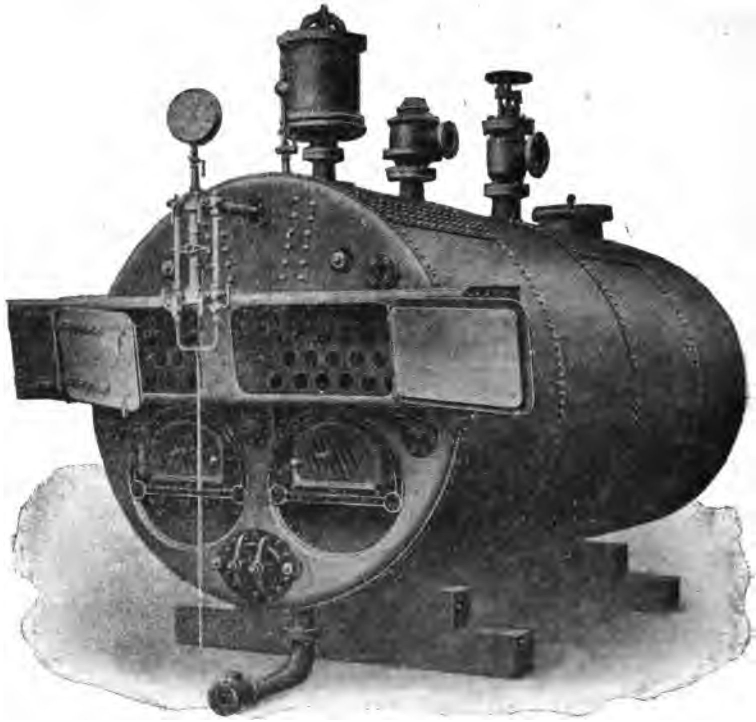


FIG. 87.—Horizontal multitubular boiler.

TABLE 15.—STANDARD SIZES OF HORIZONTAL MULTITUBULAR BOILERS.

Nominal Horse-power.	10.	15.	20.	25.	30.
Length of boiler	7′ 0″	9′ 0″	9′ 6″	10′ 0″	12′ 0″
Diameter of boiler	5′ 0″	5′ 0″	5′ 6″	5′ 9″	6′ 0″
,, ,, furnace tubes . .	2′ 4″	2′ 4″	2′ 9″	2′ 11″	3′ 0″
Number of smoke tubes . . .	48	48	54	60	60
Diameter of smoke tubes, inches .	2·5	2·5	2·5	2·5	2·75
Heating surface, sq. feet . . .	238	312	372	479	560
Grate surface, sq. feet . . .	9·2	9·7	12·5	14·0	16·5

Nominal Horse-power.	35.	40.	45.	50.
Length of boiler	12′ 0″	12′ 6″	13′ 0″	14′ 0′
Diameter of boiler	6′ 6″	7′ 0″	7′ 6″	7′ 6″
,, ,, furnace tubes . .	3′ 3″	2′ 0″	2′ 3″	2′ 3″
Number of smoke tubes . . .	60	70	70	70
Diameter of smoke tubes, inches .	3	3	3·5	3·5
Heating surface, sq. feet . . .	623	769	926	997
Grate surface, sq. feet . . .	18·0	22·0	25·8	27·0

The Hudson Patent Boiler.

This boiler is constructed in two distinct types. For large evaporations, the cylindrical element consists of a short two-flued boiler of the Lancashire type, and for smaller requirements it is of the single-flued or Cornish type. In either case, the cylindrical element is flanked on each side with a nest of water-tubes, set low down in the front and rising towards the back end of the boiler. The bottom header of each nest of tubes is connected to a mud drum at the fore end of the cylindrical element, by a mild steel pipe of large capacity. A tee pipe connects each back header, from a point just below entrance of top row of tubes, to the back end of the boiler immediately above, and between, the furnace flues. From a steam-pipe on top of each back header, a bend-pipe, of ample capacity to carry off all the steam generated in each water-tube element, connects separately with the steam space of the cylindrical element. The water-tubes are expanded into the tube plates, after which the ends of the tubes are bell-mouthed.

Each header is provided with a manhole door, which affords access for inspecting and cleaning the tubes. The general design of the boiler will be seen from the illustration in Fig. 88. At the back end, the header ends are in the form of bolted and jointed covers, and these can be easily removed in the case of tubes requiring replacing. The covers have a manhole fitted as in the case of the lower headers. No riveting or tube-expanding is required to be done at the site, as the boiler is riveted up complete and all tubes expanded at the works of the manufacturers.

Operation.—The fires are made in the furnaces as usual, and the gases, on reaching the back end of the cylindrical element, pass through a port into the side flues and then sweep along and over the water tubes. Whilst passing through the side flue, some of the gases will sweep along the side of the cylindrical element, after which they pass into the main flue under the boiler and from thence to the economiser or chimney.

The water circulation is obtained by feeding the water through the front end as usual; the feed water, being colder than the water in the body of the boiler, quickly finds its way to the bottom of the cylindrical element, and thence passes into the water-tube elements through the connections mentioned above. When the water reaches the bottom drums of the tube elements, it rises through the tubes into the top drums, and from these through an equalising tee pipe into the back end of the cylindrical element. Thus a constant and

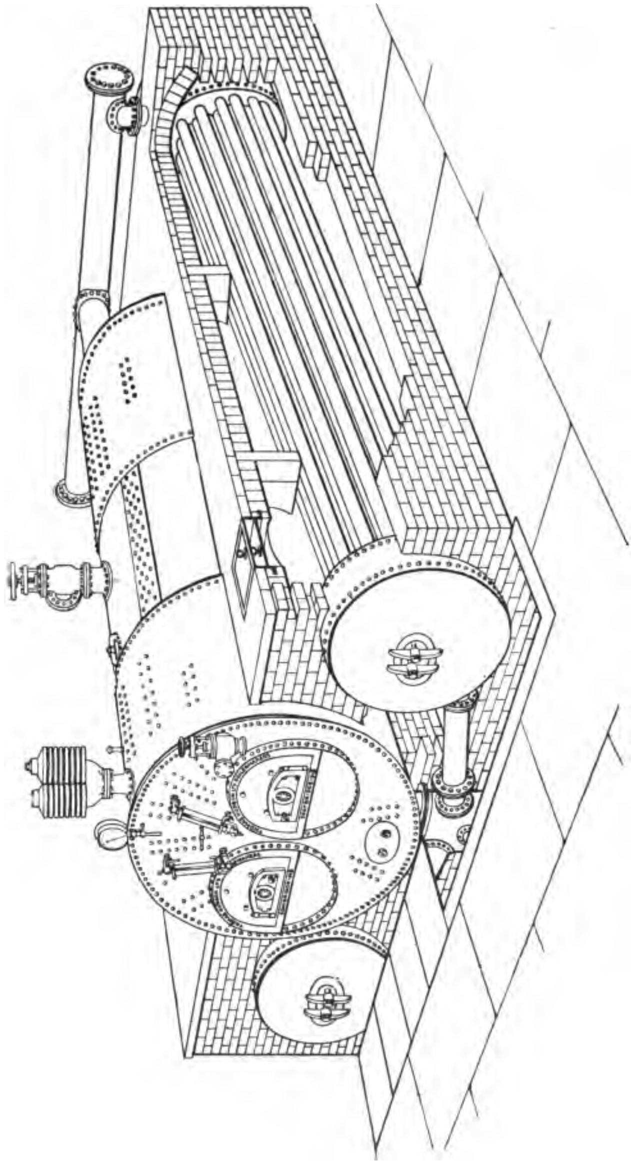


FIG. 88.—Hudson's combined cylindrical and water-tube boiler.

rapid circulation is maintained throughout the boiler, and by the time the water has arrived in the upper drum of the tube element most of it will have been raised to evaporating point, and the steam generated in the tubes will pass through the bendpipes joining the headers with the steam space of the cylindrical element. This method of circulation is claimed to keep the temperature uniform throughout, and thus prevent any strains due to unequal expansion and contraction.

The specially designed mud-drum at the front of the cylindrical part collects the sludge and scale-forming matter deposited by the water before entering the side tubes, which are kept free from scale. There is no risk of burning out of these tubes as they are not in contact with the hottest gases. The boiler possesses considerable water capacity in the cylindrical element, and so has plenty of room for the steam to get away from the surface of the water in a dry state. The thermal storage of the boiler is said to be equal to that obtained in a Lancashire type of boiler twice its length, owing to the rapidity with which the tube elements will heat up the water they contain, and to the fact that the water contained in the cylindrical element is of a uniform high temperature throughout.

TABLE 16.—STANDARD SIZES OF HUDSON BOILERS.

Economical Range of Evaporation in Lbs. per Hour.	Dimensions.		Heating Surface, Sq. Ft.	Grate Area, Sq. Ft.	Space Occupied.	
	Cylindrical Element.	2 Water-tube Elements, each Consisting of			Width over Brickwork.	Length over Brickwork.
14,000 to 17,000	16′ 0″ × 9′ 0″	57 tubes 4″ o/d.	2520	52·0	21′ 3″	20′ 6″
12,500 „ 14,500	16′ 0″ × 8′ 6″	45 „	2100	47·5	19′ 9″	20′ 6″
11,500 „ 13,500	16′ 0″ × 8′ 0″	45 „	2050	44·5	19′ 0″	20′ 6″
10,000 „ 12,000	16′ 0″ × 7′ 6″	40 „	1840	41·0	18′ 0″	20′ 6″
9000 „ 11,000	15′ 0″ × 7′ 0″	37 „	1610	37·0	16′ 9″	19′ 6″
7000 „ 8000	15′ 0″ × 7′ 0″	25 „	1120	26·0	16′ 3″	18′ 9″
6000 „ 7000	15′ 0″ × 6′ 6″	22 „	1000	23·5	15′ 9″	18′ 9″
5000 „ 6000	14′ 0″ × 6′ 0″	21 „	890	19·2	14′ 6″	17′ 9″
4000 „ 5000	12′ 0″ × 5′ 6″	21 „	750	17·5	14′ 0″	15′ 9″
3000 „ 4000	12′ 0″ × 5′ 0″	16 „	600	16·0	13′ 6″	15′ 9″

The five larger sizes are of the Lancashire type, and the five smaller are the single-flue or Cornish type.

Evaporative Tests of Hudson Boilers.—The following test was taken from one of two boilers fitted with stokers and superheaters.

Size of Boiler.

Lancashire boiler, 16 feet long, 8 feet 6 inches diameter.
Two water-tube elements, each with 45 4-inch tubes.
Total heating surface, 2209 sq. feet.

Date of test	1st January, 1917.
Duration of test	4 hours.
Weight of feed water per hour	13,253 lbs.
" " " " from and at 212° Fah.	16,235 "
Temperature of feed to economiser	58° Fah.
" " " " boiler	155° "
Gauge pressure, lbs. per sq. inch	70·88
Absolute pressure, do.	85·5
Fuel fired per hour	1582 lbs.
Calorific value of 1 lb. of dried fuel, B.T.U.	13,150
Water evaporated per lb. of fuel as fired	8·38
Equivalent evaporation from and at 212° Fah. per lb. of fuel as fired (boiler only)	9·14 lbs.
Moisture in fuel as fired	10·96 per cent.
Water evaporated per lb. of dried fuel	9·41 lbs.
Equivalent evaporation from and at 212° Fah. per lb. of dried fuel	10·27 "
Equivalent evaporation per lb. of carbon value of fuel from and at 212° Fah.	11·32 "
Temperature of gases entering economiser	586° Fah.
" " leaving economiser	495° "
Draught	·83 in.
Temperature of steam from superheater	381° Fah.
Efficiency of boiler	77·1 per cent.
" of boiler and economiser	84·1 " "

The "Economic" or Dry Back Boiler.

The Economic or dry back boiler is illustrated in Fig. 89; it will be seen to consist of a cylindrical shell, with an internal flue, and a number of small return tubes running from end to end. A combustion chamber of brick receives the products of combustion at the back of the boiler; they then pass through the small tubes to the smoke-box in front, and finally return to the back, outside the boiler shell, through the brick flues in the setting, to the chimney. A great advantage of the brick combustion chamber at the back is that this becomes partially red-hot when the boiler is at work, thus ensuring the almost perfect combustion of the gases, and reducing the smoke to a minimum.

One of the chief reasons for the popularity and demand for the Lancashire type of boiler is the low first cost; but in instituting any comparison between the Economic boiler and the Lancashire

boiler, the question of efficiency should be considered. The installation of an economiser is unnecessary with the former boiler, because the heat left in the gases after they have been so split up, and passed in and around the boiler, is only just sufficient to create a natural draught, and is not sufficient to serve any useful purpose in an economiser.

With the Economic boiler, the tubes which form some of the most effective heating surface in the boiler can be swept daily, thus keeping them near their maximum efficiency. The operation of

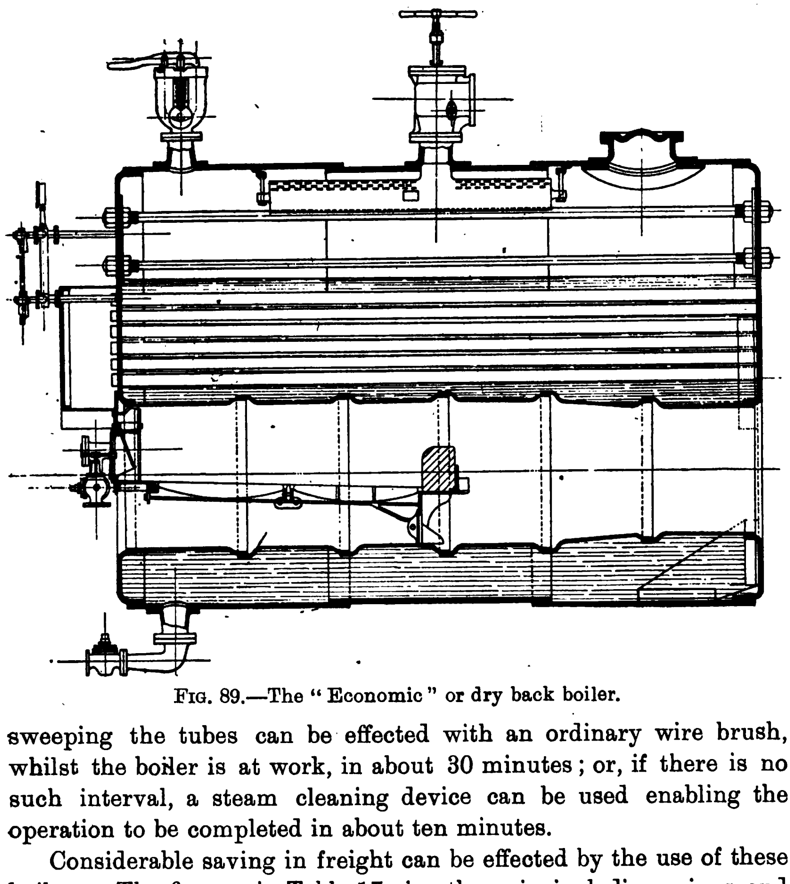


FIG. 89.—The "Economic" or dry back boiler.

sweeping the tubes can be effected with an ordinary wire brush, whilst the boiler is at work, in about 30 minutes; or, if there is no such interval, a steam cleaning device can be used enabling the operation to be completed in about ten minutes.

Considerable saving in freight can be effected by the use of these boilers. The figures in Table 17 give the principal dimensions and evaporative power of the boilers as manufactured by Messrs. Paxman of Colchester. The figures given for the evaporative capacity of each boiler are with feed at 212° Fah. when burning good coal, and with good draught and stoking.

TABLE 17.—STANDARD SIZES OF "ECONOMIC" BOILERS.

Length of Boiler.	Diameter of Boiler.	No. of Flues.	Diameter of Flues.	Internal Heating Surface.	Evaporation per Hour.	Approx. Weight of Boiler for a Working Pressure of		Approx. Weight of Fittings.		Approx. Measurement.	
						100 lbs.	120 lbs.	Unpacked.	Packed in Case.	Boiler.	Fittings in Case.
Ft. In.	Ft. In.		Ft. In.	Sq. Ft.	Lbs.	Cwt.	Cwt.	Cwt.	Cwt.	Cub. Ft.	Cub. Ft.
6 5	4 9	1	2 3	140	840	43	45	18	21	210	54
7 0	5 0	1	2 4	174	1044	48	50	19	22	252	59
8 0	5 0	1	2 6	234	1400	57	59	20	23	285	62
8 6	5 0	1	2 6	248	1480	59	61	22	25	303	66
9 0	5 3	1	2 6	276	1650	66	72	24	28	350	72
9 6	5 6	1	2 9	324	1940	78	84	28	32	420	78
9 6	6 0	1	3 0	393	2350	90	95	30	35	495	85
11 0	6 3	1	3 2	478	2860	118	130	36	41	580	100
12 6	6 6	1	3 2	565	3400	130	155	40	45	710	112
12 6	7 0	2	2 3	665	3990	164	176	53	59	807	145
12 6	7 6	2	2 4	772	4530	182	198	56	62	920	150
14 0	7 6	2	2 6	890	5220	200	220	58	64	990	160
14 0	8 0	2	2 8	1180	6960	218	242	60	67	1150	165
14 0	8 7	2	2 10	1316	7890	265	290	74	80	1320	—
15 6	8 10	2	3 0	1509	9100	310	325	78	85	1464	—
15 6	9 9	2	3 2	2015	11500	380	410	80	90	1810	—

Boiler Settings.

It is of utmost importance that care should be taken to secure a firm and solid foundation for all boilers. Unless this is obtained, many evils may arise. If the boiler sinks after it is connected up, there is the danger of breakage to the steam connections, and also the possibility of the boiler setting, cracking, or shifting. Should the outer casing of brickwork be moved in anyway from the shell of the boiler, cold air leakage may be created and serious loss of efficiency result.

A solid homogeneous block of concrete should form the base of every boiler setting, in order to ensure an efficient and lasting seat for the brickwork. The thickness of the concrete must be determined by the nature of the subsoil, and no fixed rule is possible. Where the ground is very loose it is sometimes necessary to reinforce the concrete bed with binders.

Another point of importance in connection with the seating of boilers is that every possible facility should be afforded for inspection. It is desirable that the side flues should be of ample width for inspection, and because in small flues the gases travel rapidly and the inner core of gas does not give up its due proportion of heat to the boiler plates.

The amount of brickwork in contact with the boiler plates should be as little as possible; wide contact surfaces increase the risk of external corrosion, and cover up useful heating surface.

A most effective form of boiler setting is an asbestos cushioned seating block manufactured by Messrs. Pearson, Ltd., of Stourbridge. When the boiler is lowered on to its seating, its weight compresses the cushion, which forms a perfect joint, and at the same time affords a firm and yet elastic seat for the boiler. By its means the

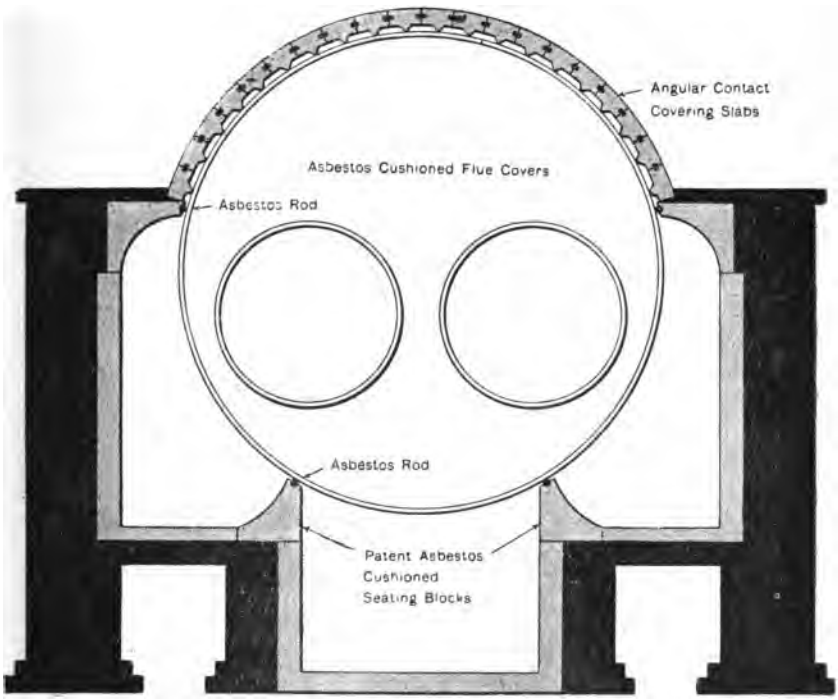


FIG. 90.—Application of asbestos cushion to side flue covers.

most effective security is provided against air leakage from the flues, and the narrow width of the joint results in only a small portion of the boiler surface being covered. Only about 8 sq. feet of the boiler plates are covered by this method, compared with about 40 sq. feet by the ordinary methods.

Fig. 90 shows the application of the asbestos cushion to the side flue covers, and Fig. 91 illustrates the longitudinal section of a Lancashire boiler, set with asbestos cushioned blocks, and square flue covers of angular contact pattern. Fig. 92 is a sectional plan

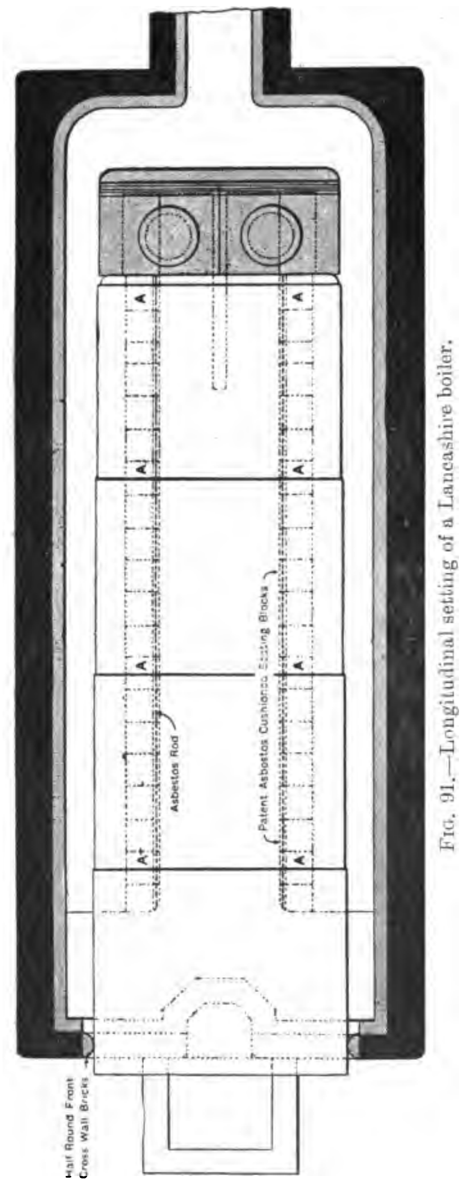


FIG. 91.—Longitudinal setting of a Lancashire boiler.

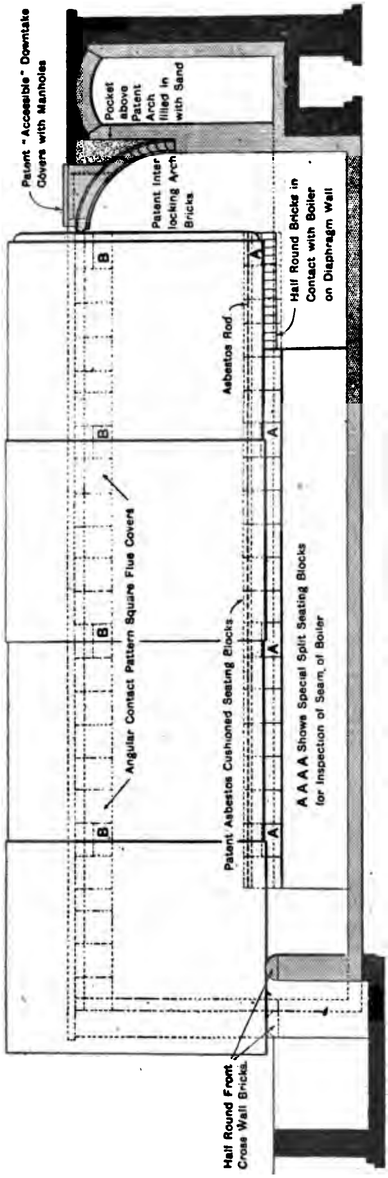


FIG. 92.—Sectional plan of Lancashire boiler setting.

showing accessible downtake covers and half round cross-wall bricks. Seam inspection seating blocks are fitted at A to facilitate inspection of the seam in the boiler shell.

Loco-Multitubular Boiler.

Fig. 93 illustrates a useful type of loco-multitubular boiler. These boilers are particularly useful for transport purposes, and are usually supplied with axles and travelling wheels, which can be removed on arrival of the boiler at its destination.

Boilers of this type have a large fire-grate, with heating surface

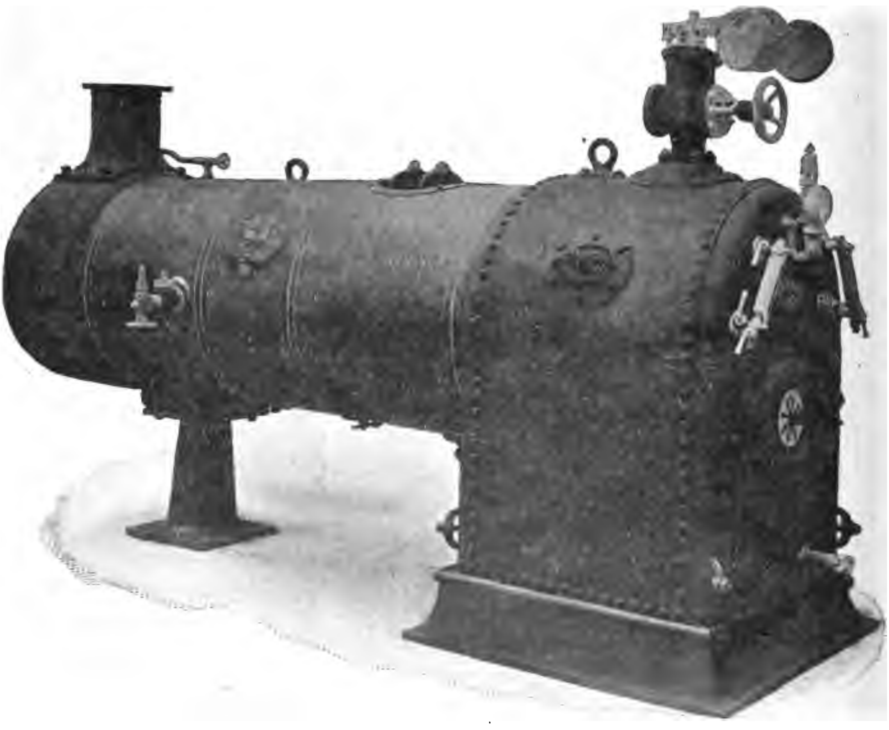


FIG. 93.—Loco-type boiler by Ruston, Proctor.

in proportion. The barrel plates are lap jointed and double riveted in the longitudinal seams. The fire-box is very strongly stayed, the stay and rivet holes being drilled through both plates at one setting.

The manhole is stiffened by a steel plate ring, which is double riveted to the boiler shell, and suitable mudholes are provided round the fire-box for cleaning purposes.

Table 18 gives a list of standard sizes for a working pressure of

115 lbs. per sq. inch, as constructed by Messrs. Ruston, Proctor of Lincoln.

TABLE 18.—STANDARD SIZES OF LOCO-TYPE BOILERS.

Heating Surface.	Length Over All.	Diameter of Barrel.	Tubes.		Weight of Boiler.	Weight of Fittings.		Cubical Measurement.		Approximate Weight of Water Evaporated per Hour, in Lbs., from and at 212° Fah.
			No.	Dia.		Unpacked.	Packed.	Boiler.	Fittings.	
Sq. Ft.	Ft. Ins.	Ft. Ins.		Ins.	Cwts.	Cwts.	Cwts.	Cub.Ft.	Cub. Ft.	
73	8 5	1 $8\frac{1}{2}$	23	2	15	7	8	68	18	175
80	8 7	1 $8\frac{1}{2}$	24	2	17	8	9	76	20	220
86	8 9	1 11	20	$2\frac{1}{2}$	19	9	10	90	22	265
93	8 9	2 $1\frac{5}{8}$	22	,,	23	11	12	100	25	300
100	9 0	2 $1\frac{5}{8}$	23	,,	26	12	13	110	28	350
117	9 4	2 $2\frac{5}{8}$	26	,,	30	14	16	135	35	440
138	9 9	2 $4\frac{5}{8}$	30	,,	32	16	18	150	40	528
159	10 6	2 $6\frac{5}{8}$	32	,,	35	17	19	162	44	615
187	11 2	2 $6\frac{5}{8}$	36	,,	40	18	20	176	46	704
221	11 6	2 $8\frac{7}{8}$	42	,,	45	20	22	200	54	880
264	11 10	3 $0\frac{3}{4}$	49	,,	56	24	27	235	58	1052
296	12 5	3 $2\frac{3}{4}$	52	,,	65	27	30	286	73	1230
354	12 8	3 $4\frac{3}{4}$	63	,,	70	30	33	320	78	1408
404	12 9	3 $10\frac{3}{4}$	70	,,	75	32	35	356	84	1584
424	13 6	3 $10\frac{3}{4}$	70	,,	88	35	38	424	88	1760
506	14 5	4 $0\frac{3}{4}$	79	,,	107	38	42	525	109	2200
582	15 0	4 $2\frac{7}{8}$	90	,,	128	42	46	592	122	2700
643	15 7	4 $2\frac{7}{8}$	97	,,	138	45	49	635	150	3150
717	17 8	4 $2\frac{7}{8}$	97	,,	152	47	52	668	175	3600
947	20 1	4 $2\frac{7}{8}$	116	,,	166	49	54	698	178	4300

The Locomotive Boiler.

The locomotive boiler has the following distinctive features:—

A **Barrel** or horizontal cylindrical shell, extending from the fire-box to the smoke-box.

A **Fire-box Shell,** the top part of which is a continuation of the barrel, the remainder being rectangular in shape and extending below and being connected to the lowest part of the barrel by means of a shoulder plate.

A **Fire-box,** rectangular in shape, and fitted inside the fire-box shell with a space at the bottom for the fire-grate and ash-pan.

The **Smoke Tubes,** connecting the fire-box to the smoke-box, conveying the hot gases through the barrel to the smoke-box and chimney.

A section of a locomotive boiler is shown in Fig. 94.

The outer plates consisting of the barrel and fire-box casing are made from mild steel, while the fire-box plates are usually constructed

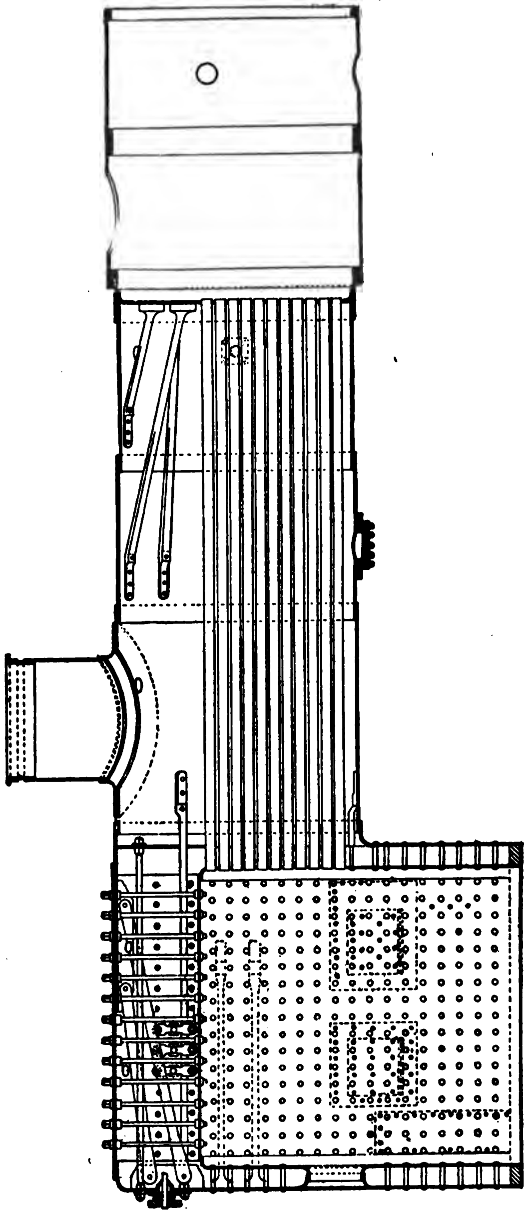


FIG. 94.—Section of locomotive type boiler.

of copper on account of its high conductivity. The smoke tubes are of brass, Muntz metal, or copper, American practice favouring steel.

The total heating surface of locomotive boilers varies from about 1000 sq. feet to 1600 sq. feet, and the grate area from 18 sq. feet to 26 sq. feet, the heating surface being approximately 60 times that of the grate area.

The coal consumption may be anything between 60 lbs. and 120 lbs. per sq. foot of fire-grate, and the draught from 2 inches to 8 inches of water pressure in the smoke-box, with 1 inch to 3 inches in the fire-box.

Working pressure is generally 175 lbs. per sq. inch, but in some cases as much as 200 lbs. per sq. inch will be found.

Dimensions.—The diameter of the barrel is usually about 4 feet 3 inches. The smoke-tubes are commonly 11 feet in length or about 80 times the diameter, between the tube plates; their diameter is about $1\frac{1}{2}$ inches, and thickness No. 10 to No. 12 W.G., the smoke-box ends being thickened to $\frac{1}{8}$ inch larger in diameter to facilitate withdrawal. When in position, the fire-box ends of the tubes are expanded and fitted with protecting ferrules, the smoke-box ends being simply expanded.

The following figures give approximate thicknesses of plates for a boiler working at 175 lbs. per sq. inch :—

Barrel . .	$\frac{9}{16}$ inch.	Fire-box . .	$\frac{1}{2}$ inch.
Fire-box casing	$\frac{9}{16}$ inch.	Fire-box tube plate	$\frac{7}{8}$ inch reduced to $\frac{5}{8}$ inch.

The barrel is usually constructed from three plates and in many cases they are arranged telescopically; the back plate is riveted to the fire-box shell and shoulder plate, and the middle plate fits into the back plate, the front plate being riveted inside the middle plate.

The circumferential seams of the barrel are single or double riveted, the longitudinal seams being butt-jointed with inside and outside straps.

The top and sides of the fire-box casing are usually constructed from one single plate, the back plate being flanged and riveted inwards; the front plate is also flanged and riveted inwards.

The top and sides of the fire-box are made from one plate; the front plate or fire-box tube plate is about 50 per cent. thicker in the perforated part than in the lower part, and the flat sides are stayed with screwed stud stays.

The smoke-box tube plate is perforated with holes to correspond with those in the fire-box tube plate, and is generally about 50 per

cent. thicker than the barrel plates, to which it is riveted by means of a turned steel ring.

The dome on the boiler is fitted to give extra steam space, and to prevent priming.

The Scotch Marine Boiler.

The Scotch, or marine return-tube boiler, consists of a cylindrical shell fitted with one or more furnaces, the latter being connected to one or more combustion chambers. By means of a number of smoke-tubes the combustion chamber is connected to the uptake.

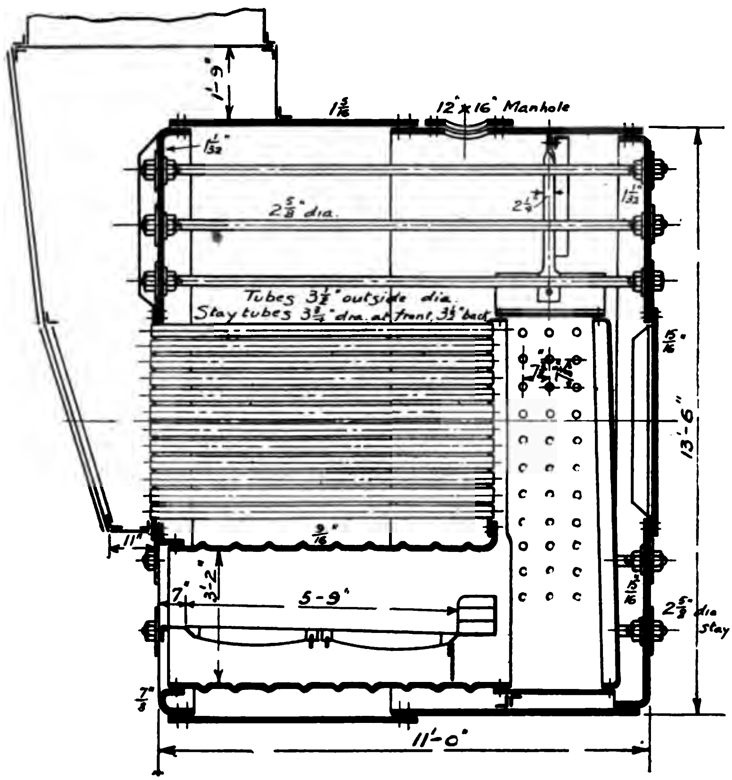


FIG. 95.—Single-ended marine boiler.

Single-ended Boilers.—Single-ended boilers constructed with two or three furnaces may have one combustion chamber for all furnaces, or a separate combustion chamber for each furnace. Single-ended boilers with four furnaces are generally constructed with two combustion chambers, although in some cases three are fitted. In the latter case, the two centre furnaces terminate in a

middle chamber, the wing furnaces being provided with separate chambers.

A section through a single-ended return-tube boiler is shown in Fig. 95. The outside diameter of the boiler is 13 feet 6 inches, and the length 11 feet. The boiler shell is of steel $1\frac{5}{16}$ inch thick; it is

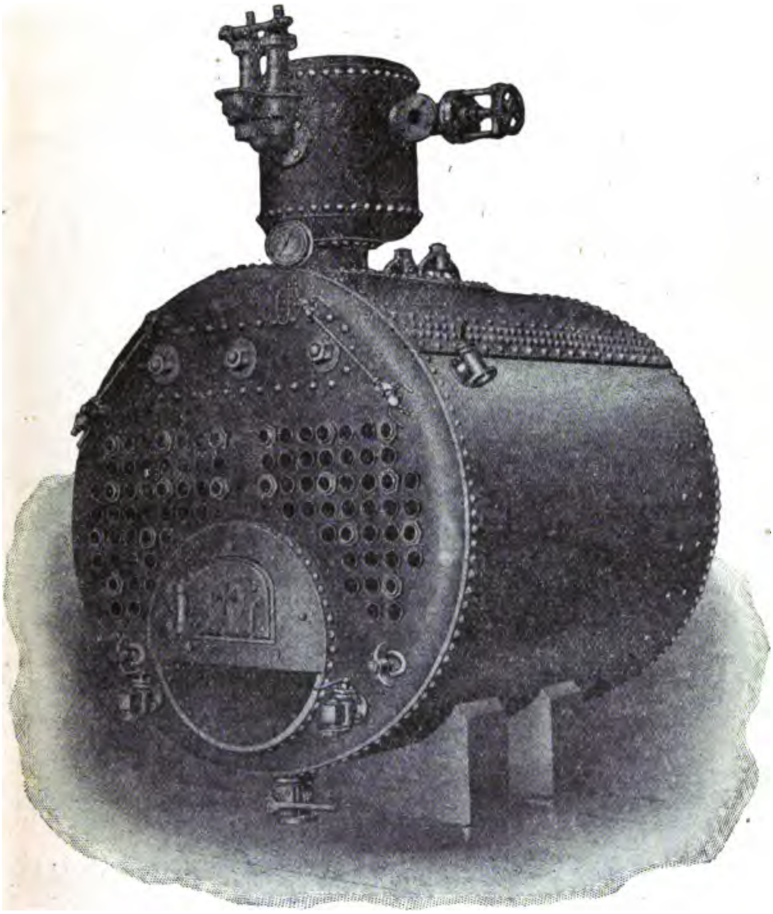


FIG. 96.—Single-furnace marine boiler.

formed with two rings, each ring consisting of two strakes, and the weight of each plate is about 2 tons 16 cwts. The smoke tubes are $3\frac{1}{2}$ inches in diameter, with stay tubes $3\frac{3}{4}$ inches in diameter, and the total number of tubes is 230, each being 7 feet 4 inches in length between the tube plates; the tubes are 0·165 inch in thickness, with the front ends swelled out to 0·227 inch.

The stay tubes are $\frac{1}{4}$ inch thick at the bottom of the thread, the diameter in the back tube plate being $3\frac{1}{2}$ inches, and $3\frac{3}{4}$ inches in the front tube plate. The shell plates are all bent cold, the rivet holes being drilled when the plates are in position. They are riveted together by double butt-straps $1\frac{1}{16}$ inch thick, the rivets having a pitch of $8\frac{1}{2}$ inches. Longitudinal stays are fitted in the steam space, $2\frac{5}{8}$ inches in diameter, with screwed ends threaded 8 to the inch.

A single-furnace marine boiler with the position of the stay tubes

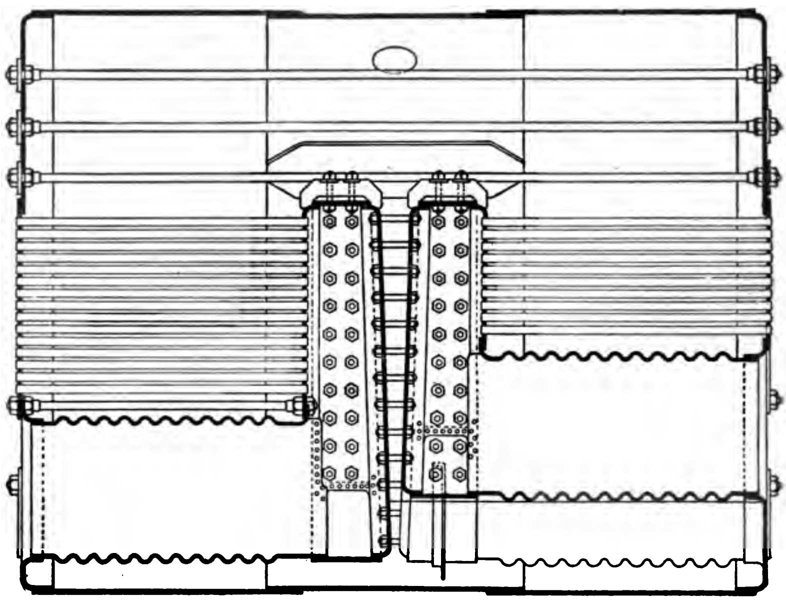


FIG. 97.—Section of double-ended marine boiler.

clearly shown, and also the feed valves, water-gauge fittings, and safety valve, will be seen in Fig. 96.

Double-ended Boilers.—The double-ended marine boiler is provided with furnaces at both ends, and is practically the same as if two single-ended boilers were placed back to back, with the end plate of each removed. In the older type of boiler, one combustion chamber was provided which was common to all the furnaces; this method is now seldom adopted, the usual arrangement now being to fit a combustion chamber to the furnaces at one end only, or to have a separate combustion chamber for each furnace. A section of a double-ended boiler will be seen in Fig. 97.

Three-furnace Boiler.—A modern three-furnace Scotch boiler by the Central Marine Engine Works, Hartlepool, is illustrated in Fig. 98. The shell plates are bent to shape, welded at the ends of the longitudinal seams, and flanged by means of specially designed flanging machines, after which they are placed in a large gas-fired furnace to be annealed.

The shells can be made in a single strake for boilers up to 10 feet

FIG. 98.—Three-furnace Scotch marine boiler.

9 inches in length, and although the cost of single-strake boilers is generally more than those of the same size with two strakes, the extra cost is a good investment.

The end plates of small boilers, when practicable, are each made in one piece; in larger boilers, the two plates forming the end plate are welded at the corners of the seams so as to form one flat circumferential surface for contact with the flanged shell plate, which forms a broad bearing surface for making a secure joint, similar to the jointing surface between a cylinder cover and a cylinder.

The rivets holding the end plate to the shell are placed longitudinally in relation to the centre line of the boiler, and being in tension, they are in the best position to resist the movement of the plate due to constant expansion and contraction of the boiler when under steam, and the absence of rivets under the bottom of the shell is an advantage readily realised and appreciated.

Fig. 99 illustrates a single-ended boiler constructed in the manner mentioned above.

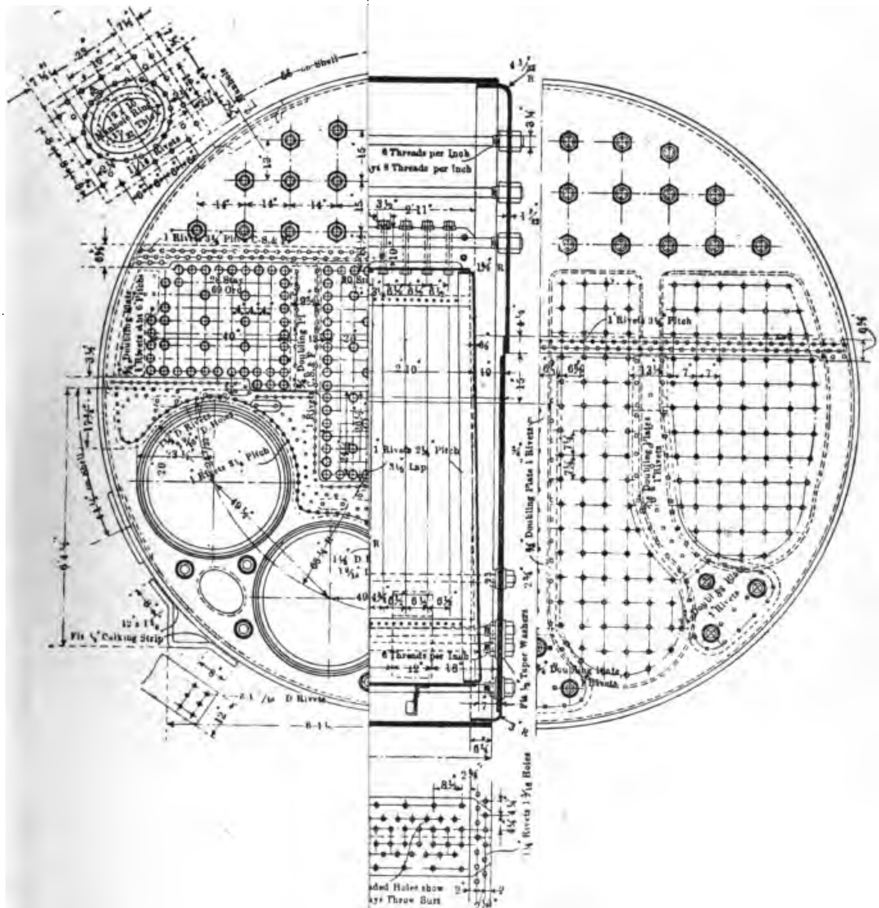
Another three-furnace single-ended boiler is shown in Fig. 100.

FIG. 99.—Single-ended marine boiler.

The diameter 14 feet 2 inches, and the length 12 feet. The working pressure is 180 lbs. per sq. inch, and the boiler is fitted with three 3 feet 6 inch Morrison furnaces, $\frac{35}{64}$ of an inch thick, each furnace having a separate combustion chamber. The smoke-tubes, of which there are 323, are $2\frac{3}{4}$ inches in diameter.

The total heating surface of the boiler is 2206·5 sq. feet, the tubes having 1844 sq. feet; furnaces, 132·5 sq. feet; combustion chambers, 230 sq. feet. The fire grate has bars 5 feet long and the grate surface is 52·5 sq. feet, making a ratio of heating surface to grate surface of 42·02 to 1.

Plate III. illustrates a four-furnace Scotch boiler 15 feet 8 inches



[*To face page* 130.

Modern Steam Boilers.]

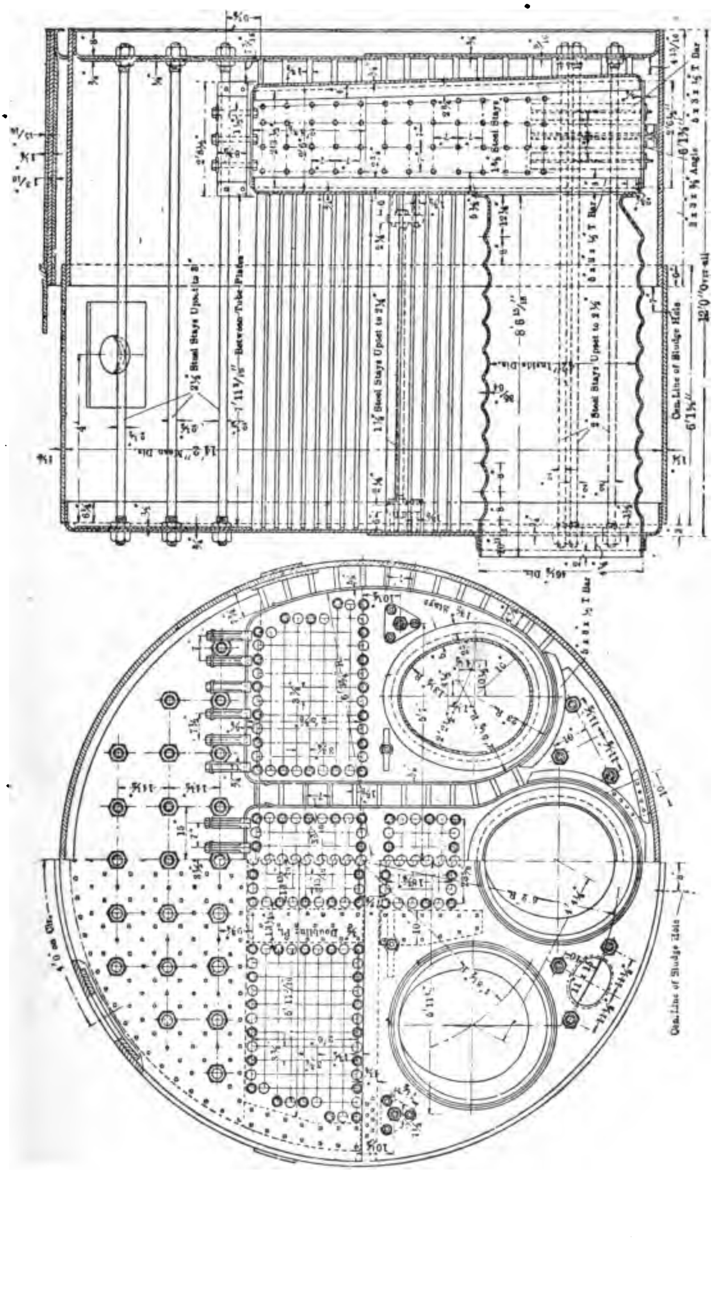


FIG. 100.—Three-furnace single-ended marine boiler.

diameter and 12 feet long. The heating surface is 2843 sq. feet, made up as follows: tubes, 2293 sq. feet, furnace, 222 sq. feet, combustion chambers, 328 sq. feet. The grate area is 73·5 sq. feet, giving a ratio of heating surface to grate area of 38·8 to 1.

The boiler shell is $1\frac{17}{32}$ inch thick. The smoke tubes are $2\frac{3}{4}$ inches outside diameter, $8\frac{1}{2}$ feet long between the tube plates, and 396 are

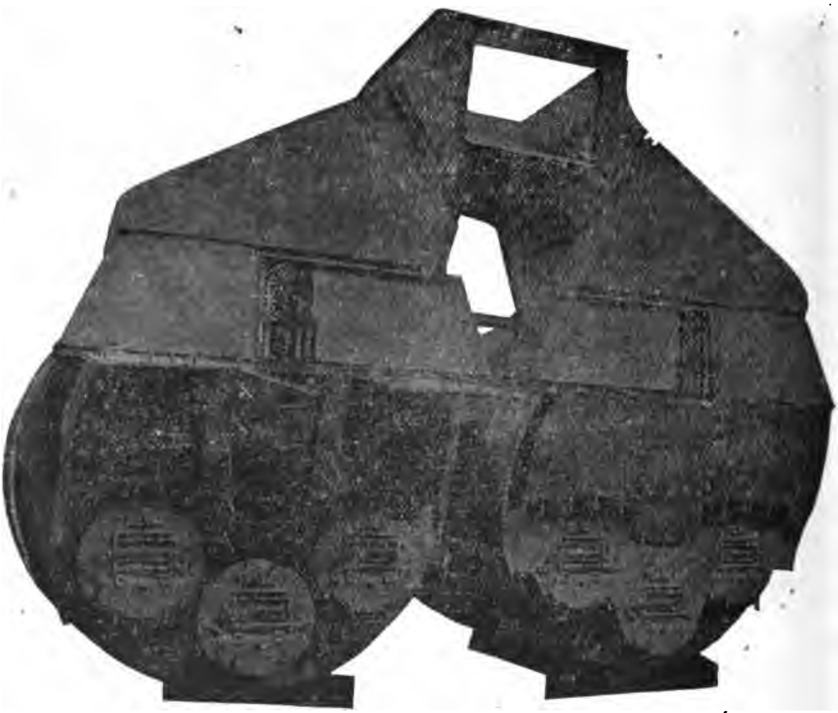


FIG. 101.—Double strake forced draught boilers showing uptake.

fitted. The furnaces are 5 feet 6 inches long and 3 feet 4 inches in diameter.

The boiler is designed to evaporate 17,270 lbs. of water per hour, or 235 lbs. per sq. foot of grate area.

Boiler with Uptake.—Fig. 101 illustrates a double strake forced draught boiler by the Central Marine Engine Works, Hartlepool; here the forced draught casings and uptakes are clearly shown.

Boilers for Small Craft.—A special type of boiler is generally constructed for dredgers and small craft, in order that the boiler should not take up too much head room, and be wholly below deck. This special type of boiler is shown in Fig. 102.

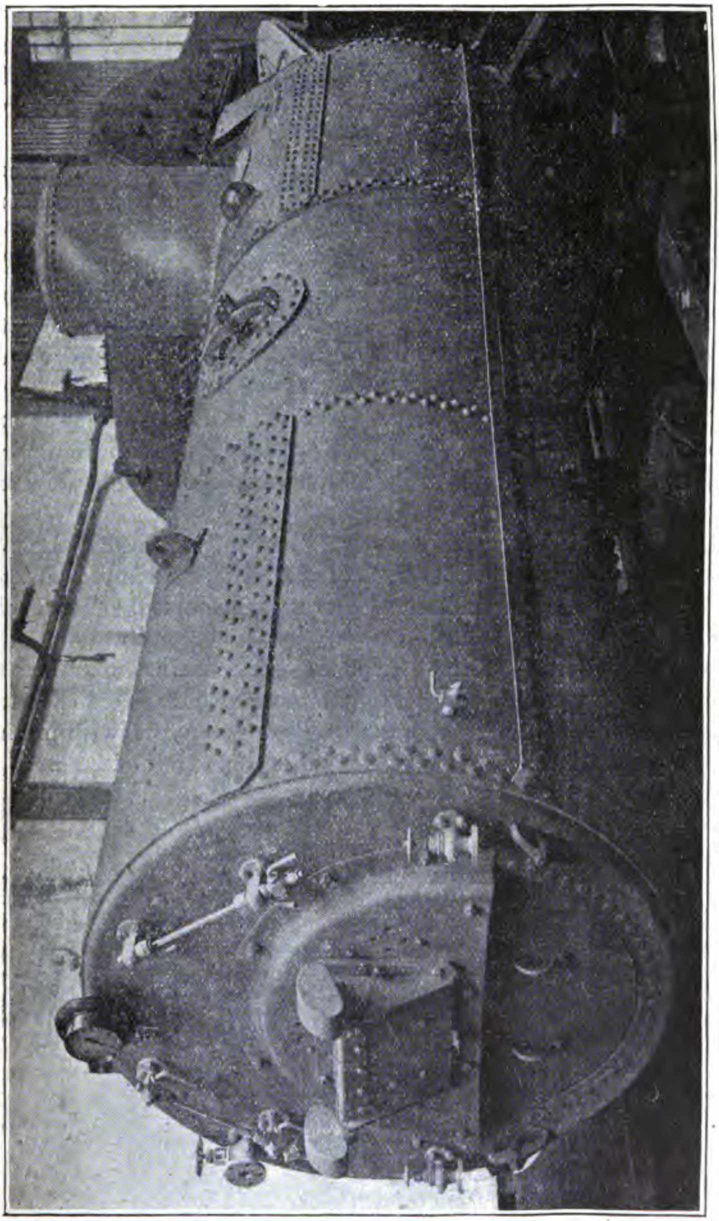


FIG. 102.—Furnace end view of a dredger's boiler.

Marine Boiler Plates.—Boiler plates are now made of very large size, and plates having a superficial area of from 500 to 600 sq. feet are common. Boilermakers state that large plates can be handled, bent, and riveted by means of modern tools, quite as easily as the smaller plates were a few years since, with the facilities then at their command.

The latest development in boiler plates is the rolling of plates with a special section, for use as wrapper plates in combustion chamber construction. Only one plate is required to form the top, bottom, and sides, and thus seams and rivets are reduced in number. The plate being made of varying thicknesses, it is possible to arrange the bending so that the thick parts of the plate are placed where extra strength is required, and where the plate is exposed to the greatest amount of heat action.

By this method the usual three-ply joint is done away with, and the one single joint necessary can be situated well away from those parts of the plate mostly influenced by the expanding and contracting action of the furnaces.

A considerable amount of trouble is frequently caused by leakage at the joints of the top, bottom, and side plates, but the improved form of wrapper plate removes the trouble, and undoubtedly extends the life of the boiler.

Marine Boilers for Land Purposes.—The multitubular marine type boiler is well adapted for land purposes where space is of importance, and many large power stations are equipped with marine type boilers. The absence of brick settings and foundations is of importance.

CHAPTER VII.

VERTICAL BOILERS.

The Cochran Boiler.

THE Cochran boiler is of the vertical type, with the furnace constructed in the form of a hemisphere. The boiler illustrated in Fig. 103 is 15 feet high and 7 feet in diameter; it has a heating surface of 600 sq. feet, and a grate area of 26·75 sq. feet.

It is fitted with 173 tubes of $2\frac{1}{2}$ inches diameter, the plain tubes being expanded and the stayed tubes screwed into both tube plates; the tubes are of iron, and are tested to 1000 lbs. per sq. inch. The boiler shown will evaporate a maximum of 4000 lbs. of water per hour with feed at 60° Fah., and steam pressure of 100 lbs., on a coal consumption of 640 lbs. per hour, but a more economical rate of working is generally recommended, as, when evaporating 3000 lbs. of water per hour with 280 lbs. of coal.

The boiler when filled to working level holds about 97·5 cwt. of water, and has thus a large heat storage capacity.

All plates used in the construction are of Siemens-Martin steel; those exposed to flame and temperature have a tensile strength of 26 to 30 tons per sq. inch, with an elongation of 23 per cent. in 8 inches; those not exposed or not flanged 28 to 30 tons with 20 per cent. elongation.

The circumferential seams are single riveted, the longitudinal one double riveted, all having lap joints. A manhole door 16 inches × 12 inches is provided in the crown of the boiler, and four 5 inch × $3\frac{1}{2}$ inch mudholes are placed at the bottom.

The only foundation necessary with this boiler is a flat hard surface.

The following are the salient points of this type of boiler:—

Design.—The furnace is of strongest possible form, i.e. hemisphere.

The water level is well above the highest point of heating surface; and the hottest part of the heating surface, the furnace, is most deeply submerged, thus making for safety.

The tubes are all of one length, and are easily swept from the smoke-box, both ends being readily accessible for expanding.

The heating surface is large in proportion to the floor space occupied, and the grate surface is large in proportion to the former,

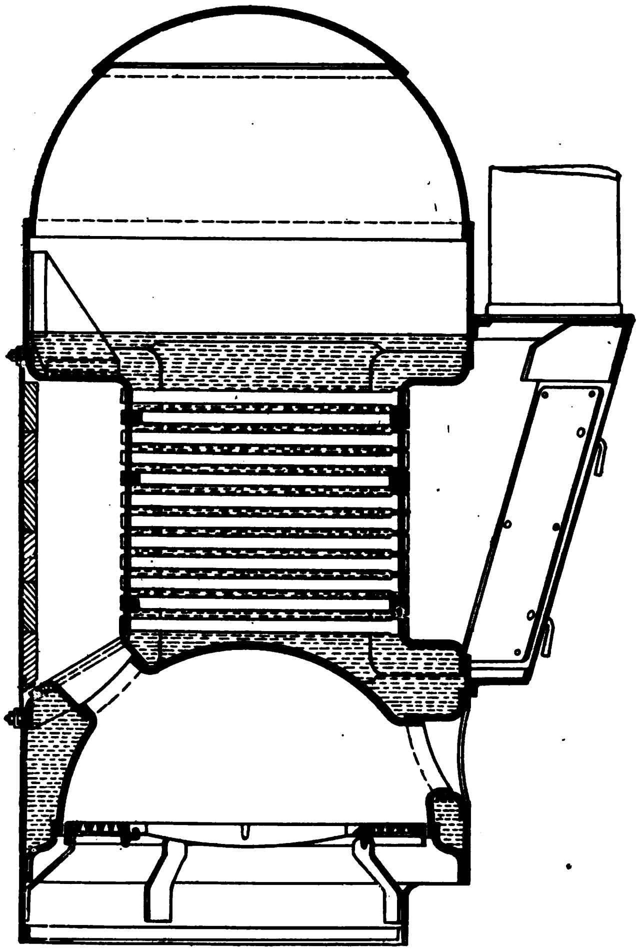


FIG. 103.—Cochran vertical boiler.

thus enabling the boiler to be worked at a low rate of combustion; the boiler is therefore an economical one. No stays or obstructions are placed in the steam space of the boiler, the space between the nest of tubes and the sides of the boiler permitting easy access to the tubes and furnace.

Construction.—The furnace, the ogee or base ring, the flue pipe, the fire-hole pipe, and the tube plates, are each made out of a single plate, by hydraulic pressure, without weld or seam of any kind.

The boilers are made and standardised in twenty-two sizes from

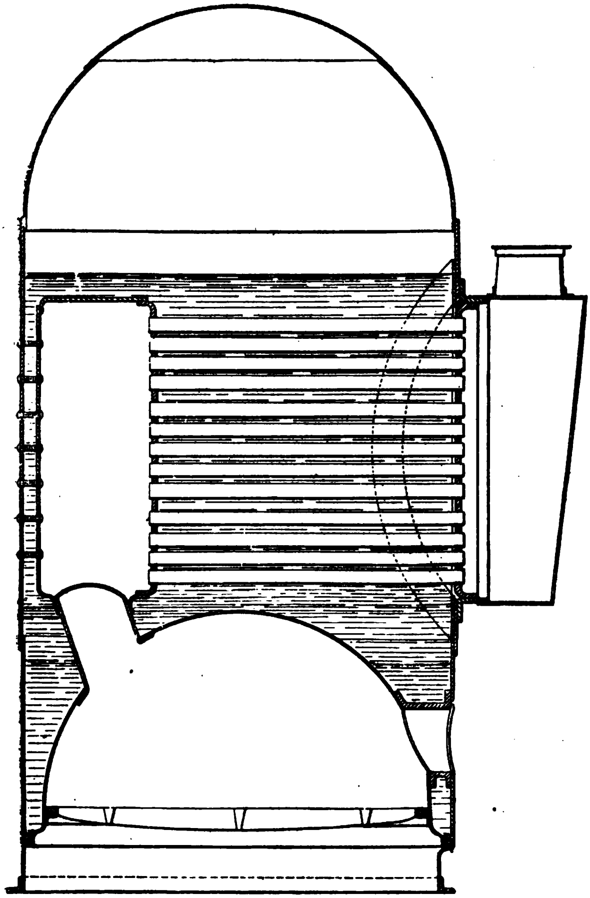


FIG. 104.—Cochran boiler.

3 feet diameter and 60 sq. feet of heating surface to 8 feet 6 inches in diameter and 1000 sq. feet of heating surface.

A modification of the standard type of Cochran boiler is shown in Fig. 104; here the smoke tubes are longer, thus giving a greater heating surface.

Evaporation of Cochran Boilers.—The following empirical formula is used to express evaporation of a Cochran boiler in terms

of grate area and heating surface, assuming that the coal which can be burnt per sq. foot grate per hour varies from about 15 lbs. in the smallest size boiler, to about 24 lbs. in the largest boiler, and that water evaporated per lb. of coal varies from about 5 lbs. in boilers which have the lowest ratio $\frac{\text{H.S.}}{\text{G.A.}}$ to about $6\frac{1}{2}$ lbs. in those which have the highest ratio.

Then if

E = evaporation in lbs. per hour
G = grate area in sq. feet
H = heating surface in sq. feet

$$E = 26(G - 2)\left(5 + \frac{\frac{H}{G} - 13}{7 \cdot 5}\right).$$

The first member of the formula represents the coal burnt per hour. The second member represents the water evaporated per lb. of coal.

TABLE 19.—STANDARD SIZES OF COCHRAN BOILERS.

Dia.	Height.	Heating Surface.	Grate Area.	Tubes. No.	Tubes. Ex. Dia.	Funnel. Dia.	Funnel. Height Recommended.	Evaporation. Heavy Steaming.	Evaporation. Easy Steaming.
Ft. Ins.	Ft. Ins.	Sq. Ft.	Sq. Ft.		Ins.	Ins.	Ft.	Lbs. per Hr.	Lbs. per Hr.
3 0	6 9	60	4·75	49	$1\frac{3}{4}$	9	11	360	270
3 3	7 6	80	5·75	54	$1\frac{3}{4}$	10	12	500	375
3 9	8 6	100	7·50	50	2	11	13	700	540
4 0	9 0	120	8·50	64	2	12	14	850	651
4 3	9 6	140	9·25	58	$2\frac{1}{2}$	13	15	1000	747
4 6	10 0	160	9·75	65	$2\frac{1}{2}$	14	16	1100	823
4 9	10 3	200	11·75	74	$2\frac{1}{2}$	15	18	1400	1050
5 0	11 3	220	12·50	84	$2\frac{1}{2}$	16	20	1520	1148
5 3	11 9	250	14·00	92	$2\frac{1}{2}$	17	22	1760	1320
5 6	12 3	300	16·75	102	$2\frac{1}{2}$	18	24	2160	1620
5 9	13 0	350	18·75	123	$2\frac{1}{2}$	20	26	2500	1878
6 0	12 6	350	18·75	110	$2\frac{1}{2}$	20	28	2500	1878
6 0	13 6	350	18·75	110	$2\frac{1}{2}$	20	28	2500	1878
6 0	14 0	400	18·75	136	$2\frac{1}{2}$	21	28	2600	2002
6 6	13 6	450	22·50	143	$2\frac{1}{2}$	24	30	3100	2358
6 6	14 0	450	22·50	143	$2\frac{1}{2}$	24	30	3100	2358
6 6	14 6	500	22·50	158	$2\frac{1}{2}$	24	30	3300	2478
7 0	14 0	500	26·75	143	$2\frac{1}{2}$	25	32	3600	2748
7 0	15 0	600	26·75	173	$2\frac{1}{2}$	25	32	4000	3015
7 6	16 3	730	31·50	216	$2\frac{1}{2}$	29	34	4800	3646
8 0	16 6	850	37·00	224	$2\frac{1}{2}$	31	38	5700	4320
8 6	17 0	1000	41·00	281	$2\frac{1}{2}$	34	40	6600	4957

Vertical Multitubular Boilers: Vertical Tubes.

A vertical multitubular type of boiler is illustrated in Fig. 105. These boilers are constructed by Messrs. the Cradley Boiler Co.

for a working pressure of 60 lbs. per sq. inch and upwards. The fire-box and shell crowns are flat and stayed by means of screwed stay tubes, which are screwed into the fire-box crown, and beaded over, to withstand the action of the fire.

The shell crown tube plate has a conical head or uptake attached,

FIG. 105.—Vertical multitubular boiler.

terminating in the chimney. The figures in Table 20 give the standard sizes and grate areas.

Vertical Boiler: Horizontal Tubes.

The type of boiler shown in Fig. 106 is extensively used for supplementary purposes on ships, and also on land where floor space is a consideration. These boilers are constructed for a working pressure of 100 lbs. per sq. inch and upwards, and where the

available space is restricted in height, they are specially constructed shorter than the standard dimensions without reducing the effective heating surface.

TABLE 20.—STANDARD SIZES OF VERTICAL MULTITUBULAR BOILERS.

Height of boiler	6′ 6″	7′ 0″	7′ 6″	8′ 6″	9′ 0″	11′ 0″
Diameter of boiler	2′ 9″	3′ 0″	3′ 3″	3′ 6″	4′ 0″	4′ 0″
Height of fire-box	3′ 0″	3′ 2″	3′ 8″	3′ 6″	4′ 0″	4′ 0″
Number of tubes	48	56	66	76	90	90
Diameter of tubes	2″	2″	2″	2″	2″	2″
Heating surface, sq. ft.	75	90	115	150	180	240
Grate area, sq. ft.	3·9	4·5	4·9	7·0	9·6	9·6
Approximate weight, cwts.	18·5	22·5	28	36	46	53

Height of boiler	11′ 6″	12′ 0″	12′ 0″	13′ 0″	14′ 0″
Diameter of boiler	4′ 3″	4′ 6″	4′ 9″	5′ 0″	5′ 0″
Height of fire-box	4′ 3″	4′ 4″	4′ 7″	4′ 8″	4′ 9″
Number of tubes	80	90	100	110	110
Diameter of tubes	2·25	2·25	2·25	2·25	2·25
Heating surface	275	325	370	420	470
Grate area	11	12·5	14·6	16·4	16·4
Approximate weight, cwts.	62	67	75	80	90

One advantage claimed over other boilers of somewhat similar design, is that the combustion chamber, being made circular, requires no stays, which are sometimes a source of trouble and always present a difficulty when cleaning or scaling has to be done. It will be seen that a water space is provided behind the combustion chamber back plate, which greatly improves the water circulation.

TABLE 21.—STANDARD SIZES OF HORIZONTAL TUBE VERTICAL BOILERS.

Nominal Horse-power.	6.	8.	10.	12.	14.	16.	18.	20.
Height of boiler	7′ 0″	7′ 6″	8′ 6″	9′ 0″	9′ 6″	9′ 9″	10′ 0″	10′ 6″
Diameter of shell	3′ 0″	3′ 3″	3′ 6″	4′ 0″	4′ 3″	4′ 6″	4′ 6″	4′ 9″
Height of fire-box	2′ 9″	3′ 3″	3′ 6″	3′ 8″	3′ 10″	4′ 0″	4′ 3″	4′ 3″
Heating surface, sq. feet	64	82	105	130	142	168	185	205
Grate area, sq. feet	5·2	5·9	7′ 0″	9′ 6″	11·0	11·5	12·5	14·0
Approx. weight, cwts.	28	34	38	48	54	57	60	72

Nominal Horse-power.	25.	30.	35.	40.	45.	50.	55.	60.
Height of boiler	11′ 6″	12′ 0″	12′ 6″	13′ 0″	13′ 6″	14′ 0″	14′ 6″	15′ 0″
Diameter of shell	5′ 0″	5′ 3″	5′ 6″	5′ 9″	6′ 0″	6′ 3″	6′ 6″	6′ 9″
Height of fire-box	4′ 6″	4′ 9″	5′ 2″	5′ 6″	5′ 8″	5′ 10″	6′ 2″	6′ 3″
Heating surface, sq. feet	254	302	350	407	450	505	552	607
Grate area, sq. feet	15·9	17·7	19·5	21·6	23·7	25·0	27·7	30·0
Approx. weight, cwts.	87	94	104	115	124	135	146	160

Hopwood Water-tube Vertical Boiler.

The general construction of this type of boiler is similar to the Marshall vertical cross-tube boiler shown in Fig. 109. They are more economical in fuel than the ordinary type of vertical boiler with cross tubes.

It will be noticed in Figs. 107 and 108 that two of the sides of

FIG. 106.—Vertical boiler: horizontal tubes.

the fire-box are flattened so as to form tube plates. A number of water tubes are carried across the upper part of the fire-box and fixed in these plates, the tubes lying a little higher at one end than the other. The tubes are placed directly over the fire, and a large amount of effective heating surface is obtained. The tubes are water tubes, therefore any scale is on the inside of the tubes and can be readily cleaned out.

The ends of the tubes are opposite two large man-holes, which have steel external covers with faced joints, as shown in the sectional

view. The fire-box leans a little to one side, which causes one end of the water tubes to lie higher than the other; the upper part of

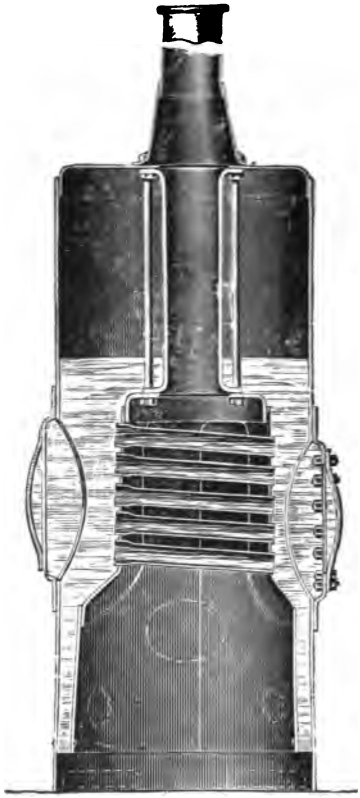


FIG. 107.—Hopwood's vertical boiler.

the fire-box is stayed to the crown of the boiler by a number of circular stays with double nuts, and the boiler is of suitable strength for a working pressure of 100 lbs. per sq. inch.

TABLE 22.—STANDARD SIZES OF HOPWOOD'S VERTICAL BOILERS.

Nominal Horse-power.	Height.	Diameter.	Number of Water Tubes.
	Ft. Ins.	Ft. Ins.	
2	5 6	2 3½	12
3	6 5	2 9	20
4	6 9	3 0	26
5	7 6	3 2½	26
6	8 0	3 5	28
8	8 1½	3 7½	28
10	9 3	4 0	34
12	9 8	4 4½	34

Marshall Vertical Boiler.

The type of vertical boiler shown in Fig. 109 is constructed entirely of mild steel, with cross tubes, and is designed for a working

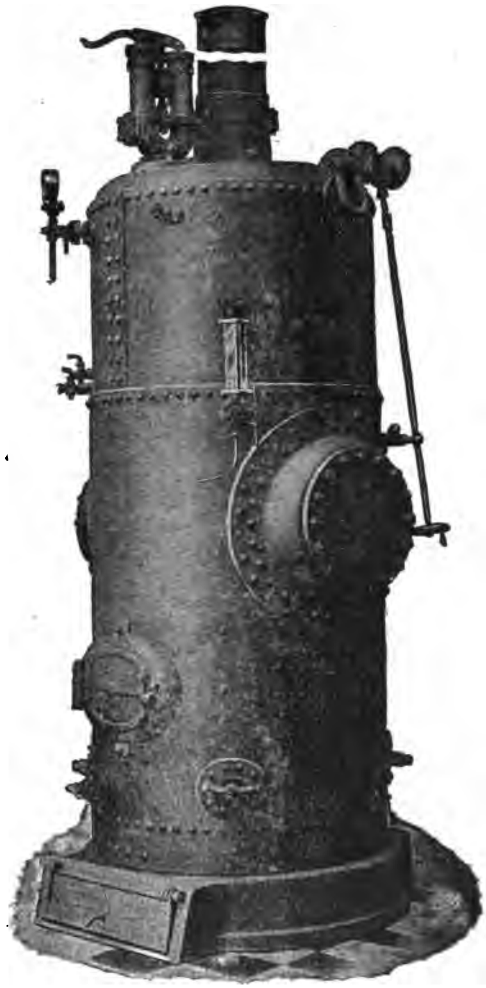


FIG. 108.—Water-tube vertical boiler.

pressure of 100 lbs. They are provided with compensating rings round each mud-hole, and have a solid foundation ring at the bottom of the water space and round the fire-hole as shown in the sectional view, Fig. 110. The uptake is of extra thickness, thus needing no cast-

iron lining, and circular stays with double nuts are provided between the crown of the fire-box and the top of the boiler.

Where space is limited, and economy in fuel is not of the utmost

FIG. 109.—Vertical boiler, cross-tube type.

importance, the cross-tube vertical boilers are very useful, as they are simple and easy to manage.

These boilers are constructed by Messrs. Marshall & Sons of Gainsborough, and the standard sizes are given in Table 23.

FIG. 110.—Vertical boiler, cross-tube type.

TABLE 23.—STANDARD SIZES OF MARSHALL'S VERTICAL BOILERS.

Nominal Horse-power.	Height.	Diameter.	No. of Cross Tubes.
	Ft. Ins.	Ft. Ins.	
2	5 6	2 3½	1
3	6 5	2 9	2
4	6 9	3 0	2
5	7 6	3 2½	2
6	8 0	3 5	2
8	8 1½	3 7½	3
10	9 3	4 0	3
12	9 8	4 4½	4
14	11 0	4 8½	4
16	12 0	5 3½	4
20	13 0	6 0	4

CHAPTER VIII.

WATER-TUBE BOILERS.

The Stirling Boiler.

THE Stirling boiler is constructed in three standard designs. In very small sizes the boilers have two steam drums and one mud drum; in intermediate sizes there are three steam drums and one mud drum. For from 1000 to 10,000 sq. feet of heating surface the boiler consists of three steam drums and two mud drums.

The main features are identical in the different designs, and Fig. 111 illustrates the largest size or five-drum boiler. The three upper or steam drums are supported by brackets carried on steel beams, which in turn rest on steel columns; these columns are built entirely independent of the brickwork, so that this may be removed or replaced without disturbing the boiler or its connections. The brick setting only serves the purpose of a housing to confine the heat and to provide furnace space.

The mud drums are suspended from the tubes expanded into them, and as they are not in contact with the brickwork, they are left free to accommodate themselves to any movement from expansion and contraction. The drums are connected by four banks of vertical tubes, while water-connecting tubes are provided between the first and second steam drums and between the two mud drums. All of the three steam drums are connected together by means of steam connecting tubes expanded into the shells in the same manner as the main tubes, while suitably disposed fire-brick baffle tiles arranged between the banks of tubes direct the gases into their proper course.

The safety and stop valves are generally connected to either the middle or rear steam drum. The feed connections are placed at the end of the rear steam drum, and access to the boiler is obtained through the manholes provided at one end of each drum.

The steam drums in the small boilers are 3 feet in diameter, and in the large boilers 4 feet in diameter; the mud drums in the smallest boilers are 2 feet 6 inches, and in all boilers, from 480 sq. feet heating surface upwards, 3 feet diameter.

The longitudinal seams are so disposed that they are not exposed to high temperatures. The drum ends are hydraulically dished to suitable radius, and each drum is provided with one manhole so that in the large boilers five manhole doors require to be removed in order

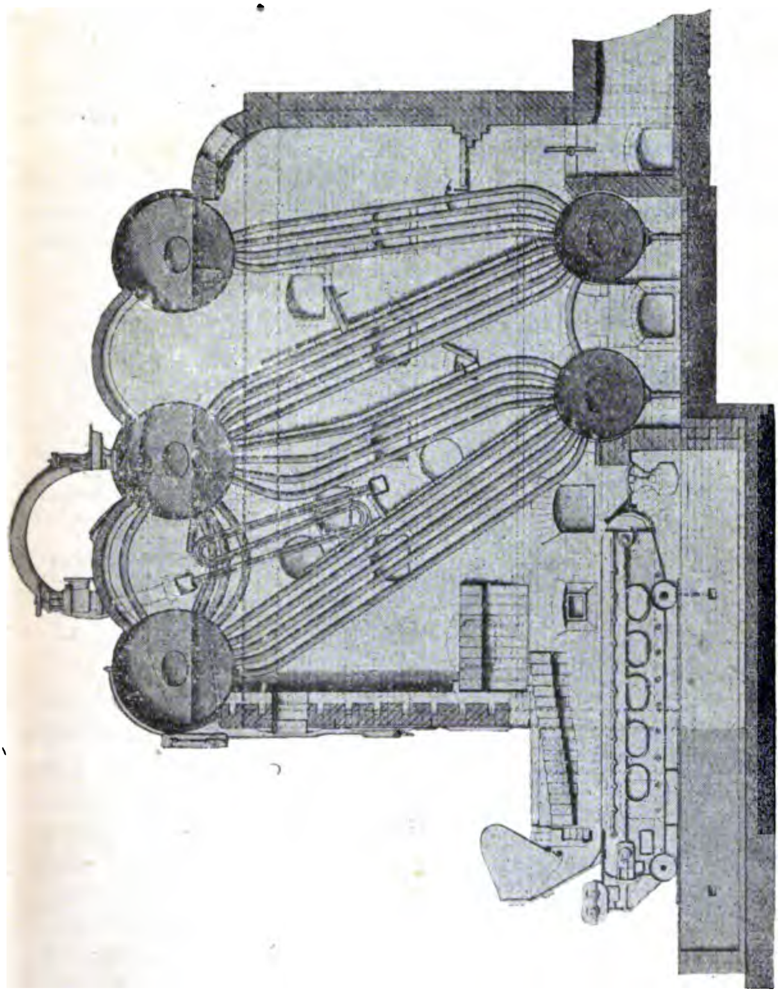


FIG. 111.—Sectional view of Stirling boiler with chain grate stoker.

to give access to all steam drums. The tubes are of weldless mild steel; they are slightly curved at the ends to permit them to enter the drums radially and to provide for free expansion of the boiler when at work. The tubes are arranged in parallel rows, and are so pitched that there is a clear passage way from end to end of the boiler, so

that any tube can be replaced without cutting or removing another tube, the method being shown in Fig. 112.

By reference to Fig. 111, it will be seen that a fire-brick arch is sprung over the grates immediately in front of the first bank of tubes. The large triangular space above the arch between the boiler front and the tubes is available for combustion chamber. The arch absorbs heat from the fire, becoming an incandescent radiating surface, which heats the air required for combustion, ignites by radiation the gases distilled from the coal, and prevents the boiler from being chilled by an inrush of cold air when the furnace doors are opened.

Circulation.—The feed water entering the rear top drum through the check valve passes into a feed distribution box, which extends the whole length of the drum. By means of this box, the feed is dis-

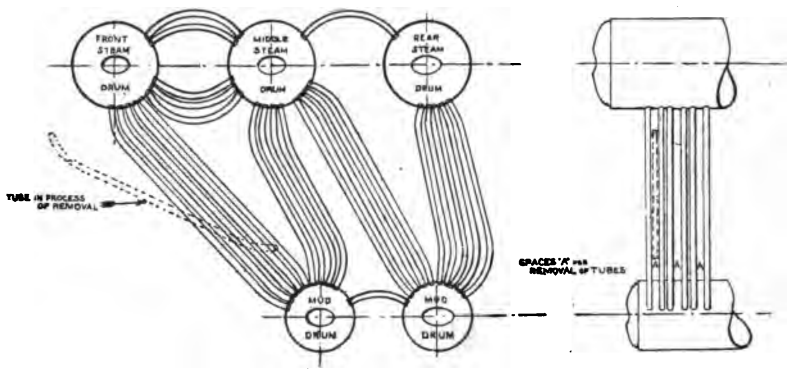


FIG. 112.—Method of inserting and removing boiler tube.

tributed over the whole width of the boiler, and ensures that all tubes receive a due proportion of the entering feed water. The feed water passes down the rear bank, up the third bank, down the second bank, and up the front bank. Here the steam formed during the passage up the tubes disengages and passes through the upper or steam circulating tubes into the middle drum, while the water passes through the lower or water circulating tubes into the middle drum. The water again joins the main circulation and passes down the second bank and up the front bank, continuing its former course until it is finally evaporated.

Course of Gases.—The gases flow in the opposite direction to the feed water; after combustion takes place in the furnace the volume of gas passes up the front bank, down the second, up the third, and down the rear to the chimney. Owing to the long distance passed

over before the chimney is reached the most intimate contact of the hot gases with the boiler surface is obtained.

Evaporative Tests.—The following figures give the result of evaporative tests under various conditions :—

	Chain Grate.		Underfeed.	Hand Fired.	
Duration of test	6 hours	6 hours	6½ hours	8 hours	7 hours
Name of firms or works where boiler was tested	Sheffield Tramway Power Station	J. Brown and Company, Limited	Eastbourne Electricity Works	Handsworth Electric Lighting Station	Hutchinson, Hollingsworth & Co., Ltd.
Heating surface in sq. feet	5320	3020	2470	1740	1740
Grate surface	90	45	49	31	37
Ratio of heating surface to grate area	59 to 1	67 to 1	50·4 to 1	56·8 to 1	47 to 1
Boiler pressure, average	156 lbs.	147 lbs.	150 lbs.	187 lbs.	160 lbs.
Class of fuel used	Shire Oaks Engine Slack	Rotherham Main Washed Nuts	Small Rheola Merthyr	Hamstead Slack	Silkstone Smudge
Method of firing	As	Above	Underfeed	As	Above
Calorific value of coal in B.T.U.	12881	14156	13022	10709	11894
Total coal fired, in lbs.	15904	6750	7311	7896	4256
Weight of ash clinker, in lbs.	—	644	—	490	402
Coal fired per hour, in lbs.	2650	1125	1125	987	608
,, ,, ,, ,, per sq. foot of grate	29·4	25	22·9	31·8	16·43
Total water evaporated	129447	67800	67076	56400	37250
Actual. Lbs. water evaporated p. hr.	21575	11300			
Actual. ,, per sq. foot of H.S. of boiler	4·05	3·6	10319 4·18	7050 4·5	5321 3·05
Actual. ,, lb. of coal	8·14	10·0	9·174	7·15	8·752
Actual. ,, lb. of combustible	—	11·1	—	—	9·66
Total water evaporated	173976	80614	70028	63700	37883
From and at. Lbs. water evaporated p. hr.	26457	13435	10773	7966	5409
From and at. ,, per sq. foot of H.S.	4·99	4·4	4·3	4·05	3·11
From and at. ,, lb. of coal	9·98	11·93	9·57	8·1	8·897
From and at. ,, lb. of combustible	—	13·2	11·09	—	9·824
Temperature of—					
Feed water	42° F.	76·5° F.	217° F.	135° F.	245° F.
Flue gases leaving the boiler	561° F.	531° F.	599° F.	634° F.	601° F.
Steam at average working pressure	368·6	—	—	—	—
Steam at superheater outlet	531·9	—	—	—	—
Amount of superheat	163·3° F.	—	100·3° F.	100° F.	—
Moisture in steam				Not	Taken
Average CO_2 in flue gases	11·66 %	—	—	13·3 %	12·25 %
Efficiency	81·3 %	81·2 %	79·3 %	77·4 %	72·25 %
,, (boiler and economiser combined)	—	—	—	—	81·38

The Heine Boiler.

The Heine boiler, illustrated in Fig. 113, is composed of a copper steam drum of large diameter, which is in some cases divided into two

smaller ones; beneath the steam drum are situated a considerable number of nearly horizontal tubes, connected at either end to flat vertical headers. Hand holes are arranged opposite the end of each tube, the cover of which is jointed on the inside, and held in position

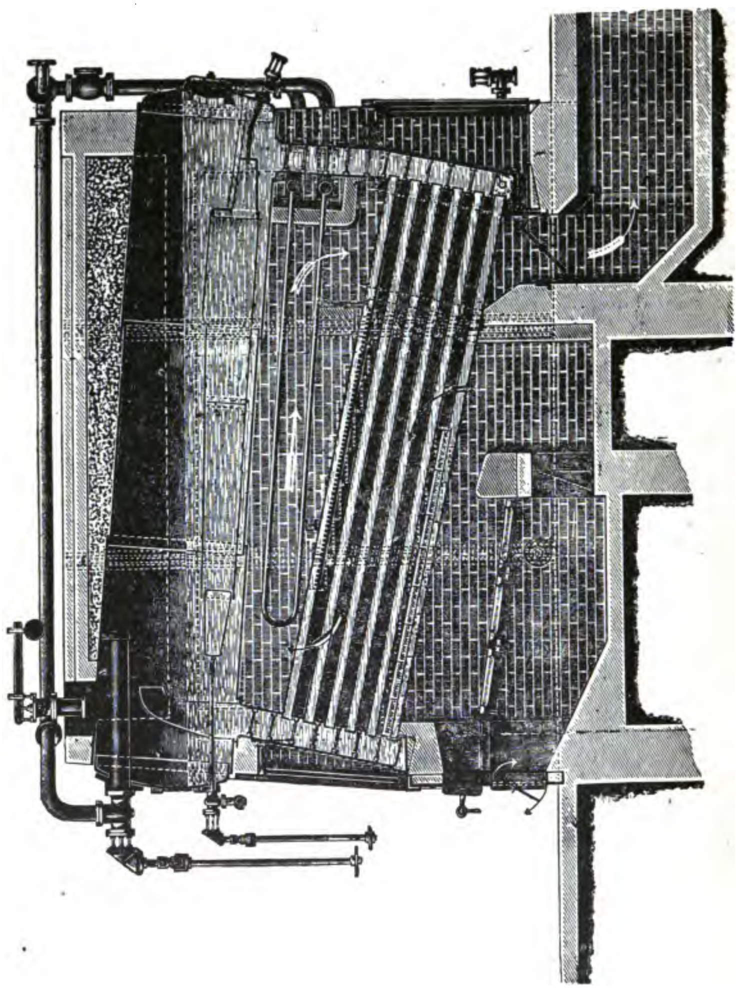


FIG. 113.—The Heine water-tube boiler.

from the outside. The boiler is slightly inclined downwards from the front end; the circulation is down the back header, through the inclined tubes, and up the front header.

The boiler seating is composed entirely of brickwork, the furnace being placed directly under the tubes. Horizontal and vertical baffles are so placed as to force the flames to circulate among the tubes before

passing to the chimney, and arrangements are made for the introduction of supplementary air to ensure combustion. The blow-off valve is fitted to the lower and opposite end of the drum to that from which the feed water enters. The internal reservoir is open for a short distance on its top side; thus the feed water is brought to the full temperature of the steam, and deposits its impurities before mixing with the other water in the boiler. The impurities are thrown down to the bottom of the internal feed reservoir, and can be blown off by means of the blow-off cock.

The following figures give particulars of an evaporative test :—

Heating surface	1407 sq. feet
Grate surface	27 ,, ,,
Ratio $\frac{H.S.}{G.S.}$	52 : 1
Boiler pressure	123 lbs. per sq. inch
Total water per hour	7·790 ,,
Evaporation from and at 212° F. per lb. of coal	10·74 ,,
Coal per sq. foot of G.S.	31·7 ,,
Temperature of gases at uptake	644° F.

The Niclausse Boiler, Marine Type.

The marine type of Niclausse boiler is illustrated in Fig. 114; it will be seen that all the evaporating tubes are fitted at one end only into the headers, a perfectly tight joint being ensured by metal-to-metal conical joints. The other end is closed by a cap and is carried by a supporting plate. The removal of any tube, either for cleaning or replacement, is very easily and rapidly effected, so that a shut-down for any cause does not put the boiler out of service for more than a relatively short time. The tubes being fixed at one end only, expansion and contraction takes place freely in all directions, giving security against troubles resulting from neglect of this important provision.

From Fig. 115 it will be seen that each header is divided into two compartments by a vertical division plate, separating the steam and water currents. The current of water flowing through the front compartment of the header is distributed to the back end evaporating tube by an inner tube contained in the former. Windows cut in the header end of the evaporating tube enable the water to enter and the steam to depart in two distinct currents, so that positive circulation is in one current only, and the correct direction is ensured.

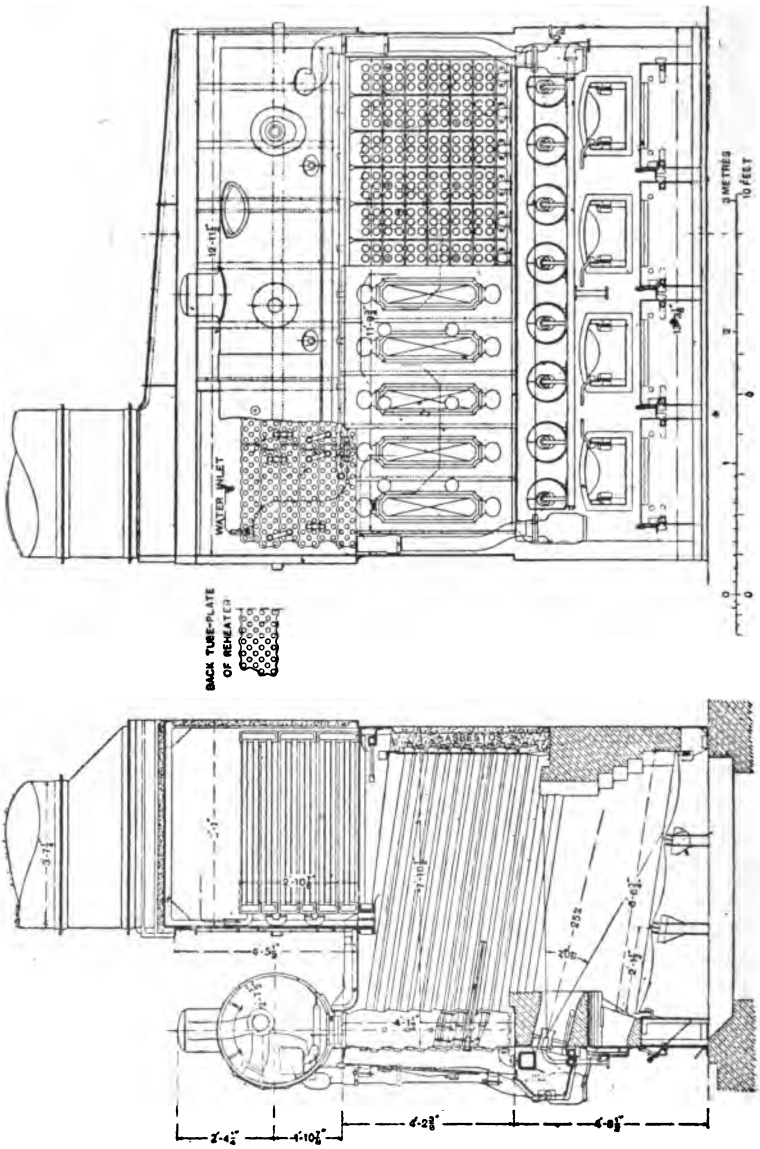


FIG. 114.—High duty marine type of Niclausse boiler.

A number of improvements have been made in the detail of the Niclausse boiler without affecting the principles of its operation and construction. The malleable cast steel curved headers are now replaced by headers constructed in solid-drawn pressed steel of rectangular section, and a special system of feed distribution to serve the lower tubes has been introduced. The lower tubes, or those nearest the furnace, are the principal evaporating tubes, and, to arrange for their special feed distribution, the steam and water drum is divided into two compartments by a longitudinal diaphragm plate in prolongation of the vertical partitions in the headers, as shown in Fig. 116; the feed water, after passing through a trough C, in which

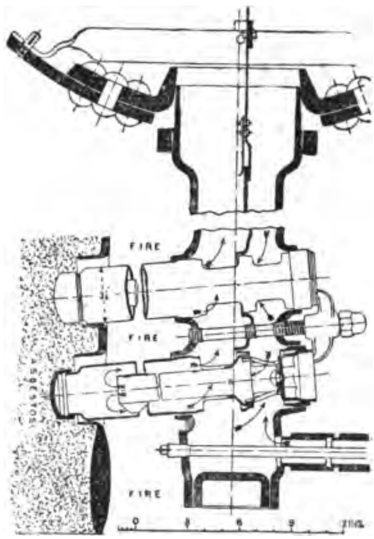


FIG. 115.—Header and evaporating tube ends of Niclausse boiler.

carbonates and other impurities are precipitated, and from which such impurities are ejected by means of a blow-down valve D, enters at the front compartment, descends the vertical headers for a certain distance determined by a cross diaphragm E, passes into the upper evaporating tubes, and returns with any steam there produced into the back compartment of the drum, which consequently contains only hot purified feed at steam temperature. The hot purified feed then descends by two tubes placed in front of the side walls, in the case of the boiler illustrated in Fig. 114 into a square horizontal header located longitudinally in front of, and connecting by an elbow to the bottom of each of the vertical headers. The upper tubes are therefore fed by relatively cool water and the bottom tubes by

purified hot water. The horizontal header also serves as a bottom box, whence impurities can also be ejected by blow-down valves F fitted at each end of it.

The lower tubes which are most exposed to the heat of the furnace consequently receive the feed at boiler steam temperature and free from any impurities which can cause deposit. Any impurities in the feed to the upper tubes are practically harmless, since the temperature of the gas surrounding them is insufficient to allow a hard scale to form.

In the land type of boiler the system is simplified, without impairing its efficiency, by suppressing the vertical down-take pipes.

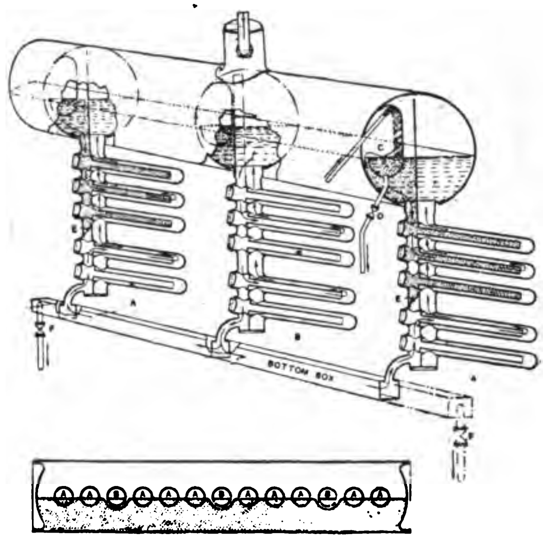


FIG. 116.—Diagram of water circulation in land type Niclausse boiler.

These are replaced by one header out of every four or five, in which no cross diaphragm is fitted in its front compartment, so that it serves to feed the bottom box and the lower tubes of all the headers fitted with the cross diaphragm, whilst its own lower tubes are served direct. The arrangement will be quite clear from Fig. 116, A being headers having the cross diaphragm in their front compartment taking partially purified feed from the front side of the drum to feed the upper tubes, and B being a down-take header taking its hot purified feed water from the back side of the drum, the division plate therein being suitably arranged for this purpose, as shown at B in the plan.

In the latest type of marine boiler, the sections of the headers have been increased, chiefly in the rear compartment forming the passage

for the steam. This is about four and a half times as large as in the earlier designs. Also an inclination of 15 per cent. instead of 10 per cent. has been given to the tubes, and both of these improvements facilitate disengagement of the steam. The outside diameter of the tubes has been reduced from $3\frac{5}{16}$ inches to $2\frac{3}{8}$ inches, a reduction which has been rendered practicable, with complete security against all forms of stress, by the above-mentioned improvements.

The boiler is fitted with an economiser placed above the tubes, and the water circulates into this apparatus on the contra-flow principle, that is, in the reverse direction to the hot gases.

In a six-hour trial at the combustion rate of 19·5 lbs. per sq. foot of grate surface, the evaporation in lbs. from and at 212° Fah. was 13·1 per lb. of coal fired, the thermal efficiency being 91·5 per cent., and the capacity practically 20,000 lbs. per hour.

In a six-hour trial at the combustion rate of 37 lbs. per sq. foot, the evaporation in lbs. from and at 212° Fah. was 11·5 per lb. of coal fired, the thermal efficiency being 79·3 per cent., and the capacity practically 41,000 lbs. per hour.

The Niclausse Boiler, Land Type.

For land service the Niclausse boiler is generally fitted with a superheater, and when desired with a mechanical stoker, both of the firm's design and make. The superheater is constructed of several serpentine sections interpolated and coupled to two headers, one at the entrance and the other at the steam exit. The serpentines, which are placed within the nest of tubes in the latter, are located above the "faisceau".

The Niclausse mechanical stoker comprises fire-bars in short sections interlocking each other and carried in supporting bearers, which are given an intermittent to-and-fro motion, so that two adjacent bars always work in opposite directions. There is a momentary cessation between the movement backwards and forwards. The bar movement is effected by means of a slowly rotating shaft with hard steel cams, which engage with hard steel trip pieces mounted on bearer heads. The speed of the driving shaft can be varied from 1 to 6 revolutions per minute. Below the grate are fitted a series of hoppers serving as both air-ducts and ash-pits. The air supply is furnished preferably by a forced draught fan working at low pressure. This system is very much more economical than either the induced or ejector draught systems. The ash-pit is divided into three compartments in which the air supply is regulated independently to the different zones of the fire-bed, whereby a good combustion with all

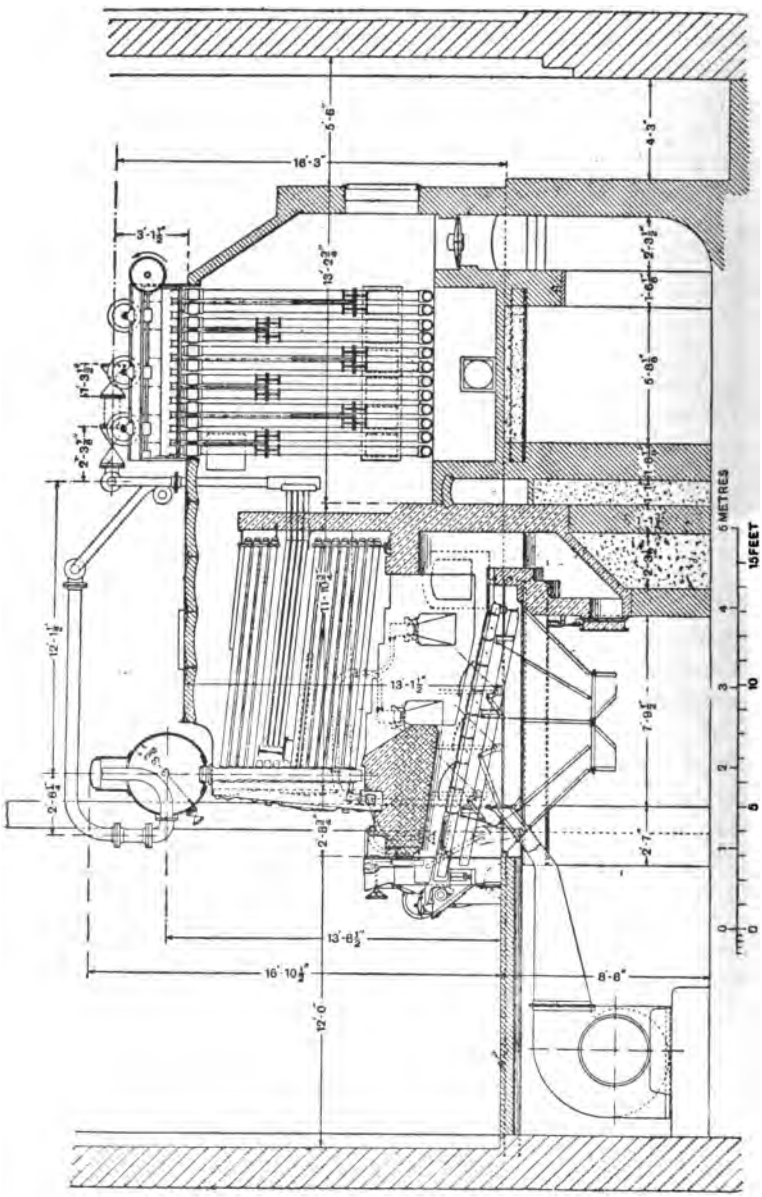


FIG. 117.—Cross-sectional elevation of land type Niclausse boiler.

classes of fuel is ensured. The ash-pit compartments also serve to separate green fuel riddlings from the fine ashes, the former being trapped in the front compartment and the latter in the rear compartment, whilst the clinkers are delivered into a capacious hopper under

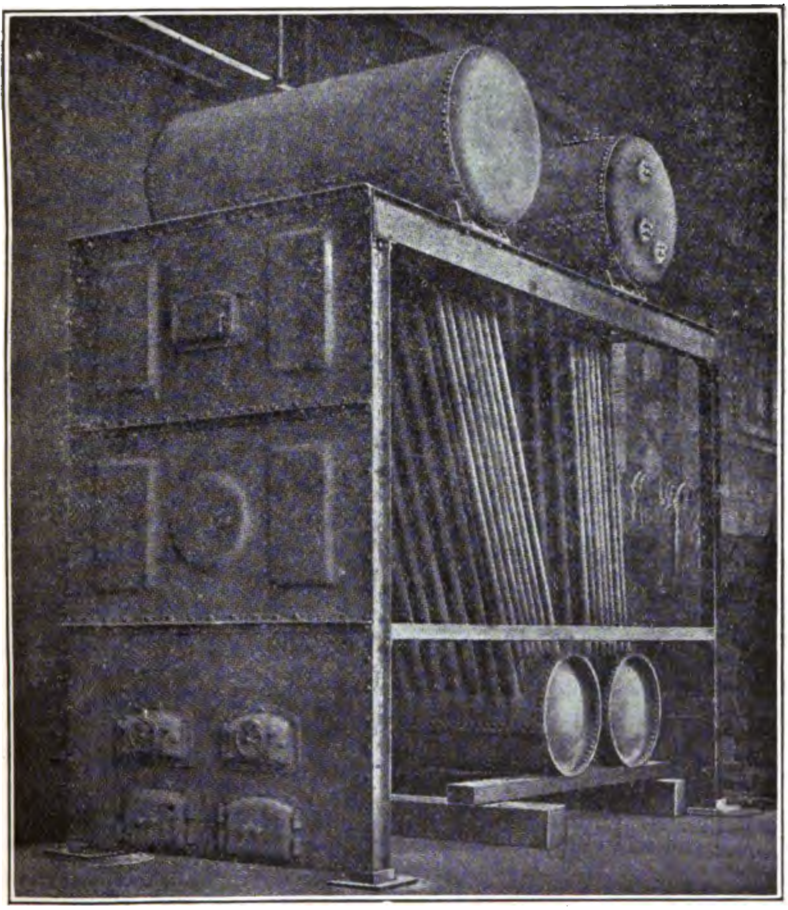


FIG. 118.—Thompson's water-tube boiler, vertical type.

the end of the grate. The Niclausse stoker has proved capable of burning all classes of solid fuels, from coke breeze and coals having only 8 per cent. volatile matter, to the coals richest in volatile matters. Fig. 117 illustrates the general arrangement of the boiler with stoker and superheater.

The Thompson Water-tube Boiler.

Two types of this boiler are constructed, one with nearly vertical tubes, and one with nearly horizontal tubes. The former type is illustrated in Fig. 118; it is suspended from mild steel girders resting on steel columns, independent of the brickwork. All the circulation tubes are perfectly straight, and any tube can be removed without disturbing its neighbour, and can be passed in and out of the boiler through the furnace door opening.

The steam and mud drums are of mild steel, and each drum is divided into halves longitudinally. The portion into which the tubes are expanded are pressed hydraulically into a series of flats, giving right-angled surface and bearing for each tube, and also retaining in

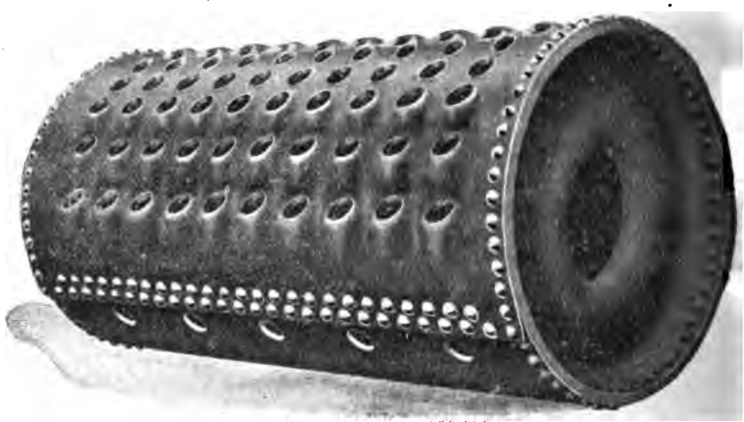


FIG. 119.—Bottom drum of vertical boiler.

the main the cylindrical form of the drum, thus allowing the heating tubes to be straight. The edges of plates are machined and the rivet holes and tube holes are drilled in position after the plates are bent to form.

The ends are dished and flanged to a suitable radius, and the front end of the upper drum has the necessary flats formed to receive the various fittings; the back ends of the drums have each a 16 × 12-inch manhole flanged inwards and faced to receive a cover.

The tubes being fitted directly into the drums, each draws its own supply of water from the storage contained in the bottom drum, and the steam generated has a maximum area for its release. The steam is therefore liberated in small jets along the whole surface of the water in the upper drum, where there is no violent ebullition.

Fig. 119 illustrates the bottom drum of the vertical type boiler.

The horizontal type is shown in Fig. 120; here all the tubes are perfectly straight, but the tubes are inclined to the horizontal, from which the type takes its name.

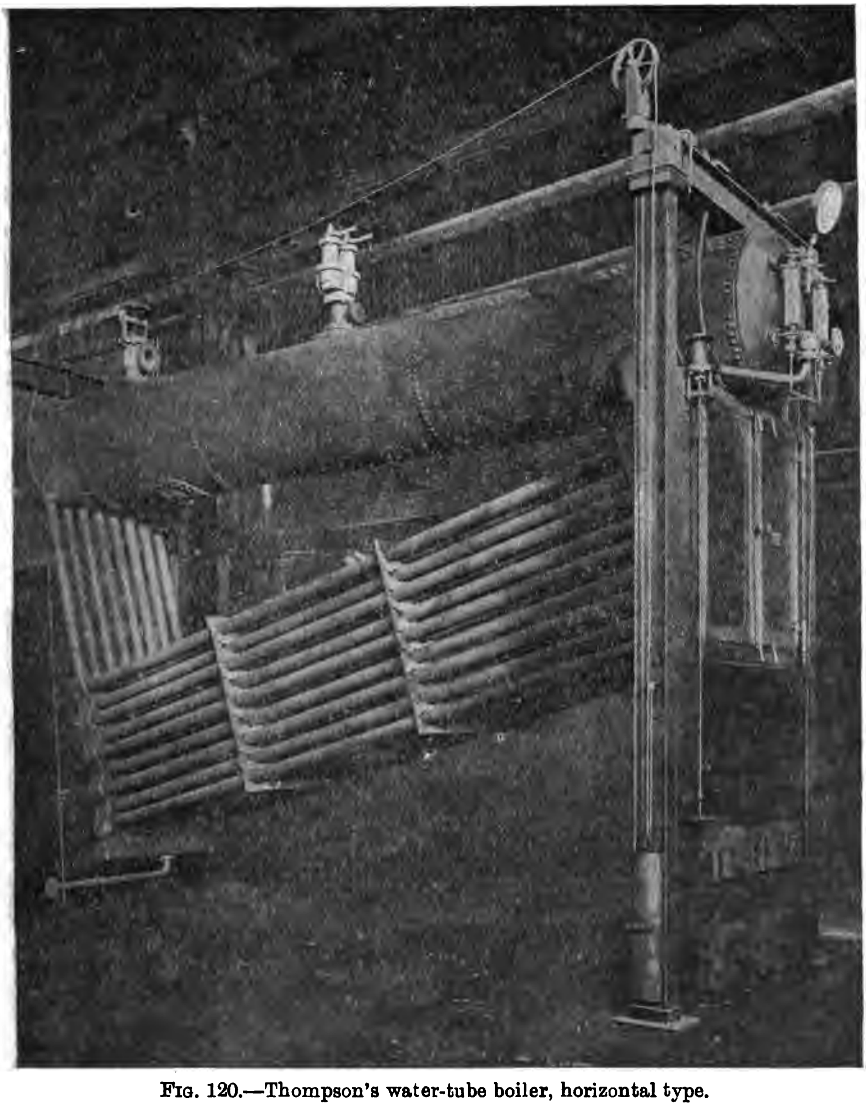


FIG. 120.—Thompson's water-tube boiler, horizontal type.

The design of this boiler is based upon the natural law of heat, that hot water tends to rise while cold water tends to fall; thus the circulation follows a continuous cycle.

Immediately opposite the ends of each tube are hand-hole fittings, the removal of which gives access to the tubes for cleaning purposes. Each tube can be inspected internally for its whole length by inserting a lamp at one end and looking in at the opposite end. Any one tube can be removed if desired without disturbing its neighbour or removing any brickwork; the tube when being removed is passed through the large tube door opening immediately in front of the boiler.

FIG. 121.—Mild steel staggered header.

The boiler consists of a series of sections; each section is made up of seamless steel tubes 4 inches in diameter, connected at the ends by the continuous wrought mild steel staggered headers, as shown in Fig. 121, or "up-takes" and "down-takes," the tubes being expanded therein. This staggering avoids straight passages for the gas between the tubes. The staggered headers are connected to the steam and water drum connecting tubes, 4 inches in diameter, one end being expanded into the headers and the other end expanded into a mild steel cross-box, as in Figs. 122 and 123, which is riveted by a double row of rivets to the steam and water drum. At the bottom of the back row of staggered headers is fitted a solid drawn mild steel mud drum, into which all the impurities are deposited, and these are blown out of the boiler by means of the blow-off valve, which is connected to the bottom of the mud drum.

The several sections of the boiler are connected each at one end to a steam and water drum, and at one end with a mud drum, by means of seamless steel tubes 4 inches in diameter and of suitable length, the tubes being expanded in the drums and headers.

The drum ends are dished and flanged to a suitable radius by means of an hydraulic press, and afterwards annealed. The boiler

is suspended from steel girders, resting on steel columns, standing in cast-iron bases. The boiler is thus suspended entirely independently of the brickwork, and allows the brickwork to be removed or replaced without disturbing the boiler or its connections.

FIG. 122.—Cross-box.

The Clarke-Chapman Water-tube Boiler.

The Clarke-Chapman water-tube boiler (Woodeson's patents) is made up of a number of sections, each consisting of a steam drum at top, a water drum at bottom, and a number of groups of tubes (the number of groups in each section depending on size of boiler required) expanded into flat discs on the steam and water drums, as shown in

FIG. 123.—Cross-box.

Fig. 124. These flat discs are pressed by hydraulic pressure out of the solid plate.

Each steam drum is connected to its neighbouring steam drum by horizontal connecting or circulating tubes, and the water drums are also connected in a similar manner.

On the top of the steam drums are arranged a series of manholes, one immediately over each group of tubes, and any tube can be withdrawn or replaced through the manhole above the particular

FIG. 124.—View of drum showing embossed tube-plates.

FIG. 125.—Manholes of steam drum.

group in which the tube is situated. A view of the manholes in the steam drums is shown in Fig. 125.

The feed water enters into the rear steam drum at the point

farthest away from the fire, and the water flows down the tubes in the rear section and up the tubes in the front sections.

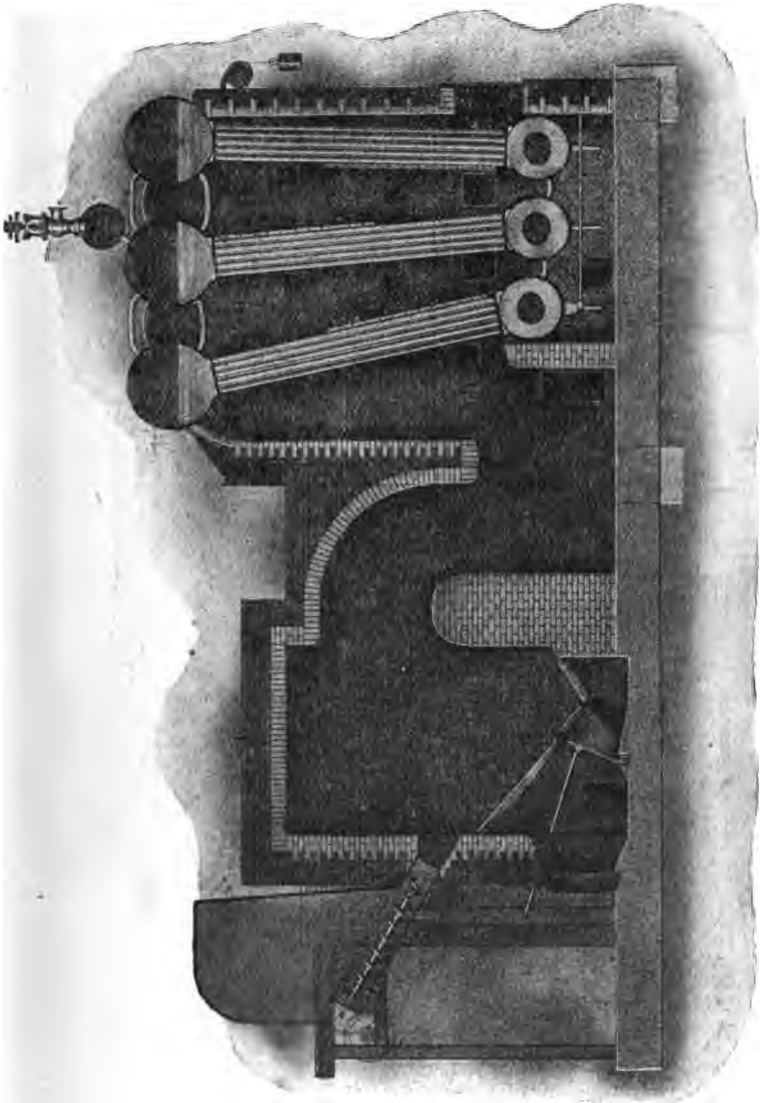


FIG. 126.—Woodeson's boiler fitted with patent hopper and feeder.

The advantage of this circulation is obvious, as the water enters the boiler at the coldest part and flows down the rear tubes in contact with the coldest gases, precipitating any mud or dirt into the bottom rear drum, and all the tubes in the front sections which are in contact

with the greatest heat have practically clean water to deal with, therefore no deposit is found in any of the tubes exposed to great heat.

The fire grate is arranged across the boiler immediately in front of the front sections, and the gases travel upwards among the tubes of the front sections and downwards among the tubes of the rear section, and out at the back wall.

A large steam dome is arranged over the steam drums to ensure perfectly dry steam being obtained.

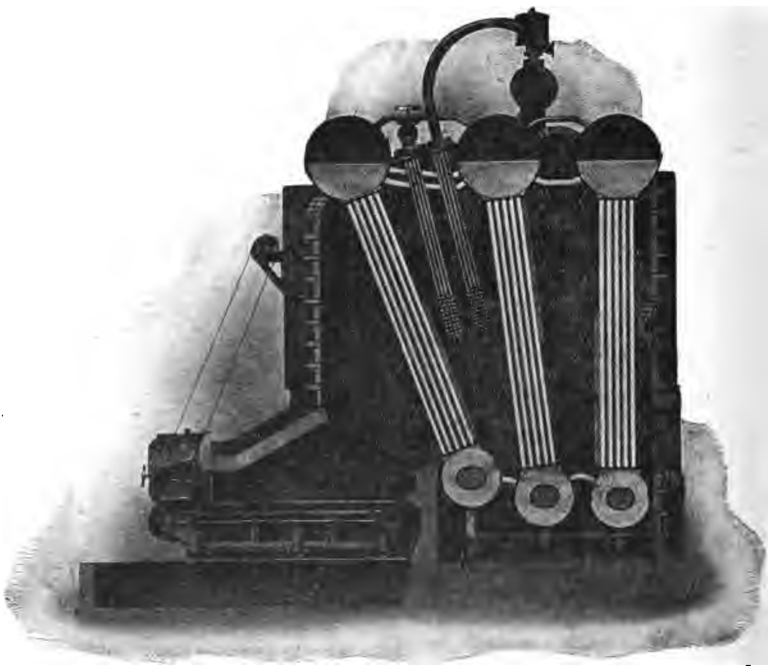


FIG. 127.—Section showing chain grate stoker.

Large doors are arranged in the walls of the boiler for access into the bottom drums, and also into the combustion spaces, for inspection, etc. Small sight-holes are also arranged in the walls for inserting a steam jet for clearing the tubes of soot.

The general design of the boiler as fitted with an integral superheater is shown in Plate No. IV.

The following advantages are claimed for this boiler:—

All heating tubes perfectly straight and nearly vertical.

No joints exposed to heat of furnace gases.

with
ther
heat

the
the
and

perf

th
et
st

he

All parts of boiler free to expand.

All heating tubes same length.

An unobstructed view through each tube for inspection.

Maximum steam release area.

Free access to all parts of the boiler.

Minimum deposit in tubes.—These tubes being nearly vertical and perfectly straight, deposits are not retained in the tubes, but are collected in the large mud drums; thus over-heating and destruction

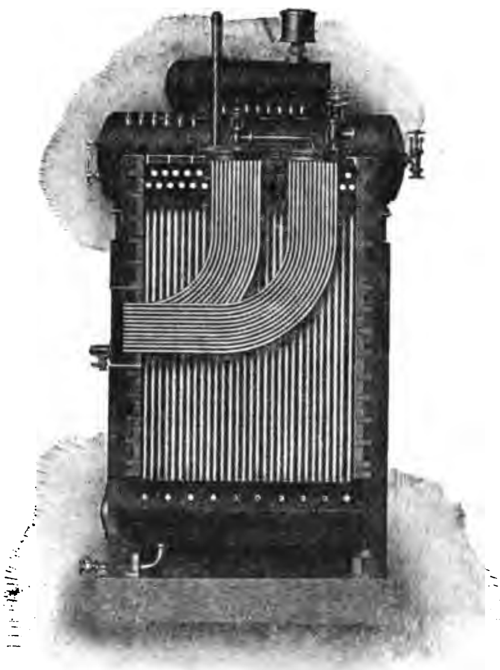


FIG. 128.—Three-section boiler with superheater.

of tubes is reduced to the minimum. This is a distinct advantage over boilers with horizontal tubes, which may burn through in the bottom rows, due to the tendency for deposits to collect in any tubes not lying horizontal, or to failure to use distilled water only; the same danger exists with vertical tubes if they are not straight, as deposit may collect at any bend.

The construction and design are simple and such that the boiler may be worked and understood by the ordinary fireman.

Large combustion chambers are so arranged that the whole of the

heat is utilised in the most economical way, and combustion of gases completed before leaving the heating surface.

The design offers great facility for cleaning, as by breaking one manhole joint on each steam and water drum the whole of the tubes can be thoroughly examined internally, and by breaking one manhole joint in steam drums, nineteen tubes are accessible for any purpose.

No complicated tools are required; the ordinary tools with which every mechanic is fully acquainted with are the only ones wanted.

The furnace arrangement of a Clarke-Chapman boiler for burning sugar-cane or other similar refuse is shown in Fig. 126. Here the specially built furnace is equipped with an Underfeed Stoker Co.'s Hopper and Feeder.

Figs. 127 and 128 illustrate the three-section type of boiler fitted with superheater and chain grate stokers.

TABLE 24.—STANDARD SIZES OF CLARKE-CHAPMAN BOILERS.

H.S. Sq. Ft.	G.A. Sq. Ft.	No. of Sect.	No. of Groups per Sect.	Length of Tubes.	Overall Sizes.			Brickwork.		Shipping.	
					Height over Steam Drums.	Width of One Boiler.	Front to Back.	Fire.	Ordinary.	Tons.	Cubic Measure.
				Ft. Ins.	Ft. Ins.	Ft. Ins.	Ft. Ins.				
1175	21½	3	2	12 6	20 9	6 3	24 0	3,500	12,400	24	1500
1225	24	3	2	13 0	21 3	6 3	24 6	3,680	12,750	25	1550
1260	26	3	2	13 6	21 9	6 3	25 0	3,850	13,100	26	1600
1350	28	3	2	14 6	22 9	6 3	26 0	4,100	13,800	27	1710
1760	35	3	3	12 6	20 9	7 10	24 6	4,400	14,500	33	2070
1820	37	3	3	13 0	21 3	7 10	25 0	4,540	14,750	34	2120
1890	38	3	3	13 6	21 9	7 10	25 3	4,680	15,000	35	2170
2025	41	3	3	14 6	22 9	7 10	26 0	5,050	15,400	36	2260
2350	47	3	4	12 6	20 9	9 5	25 0	5,200	15,800	38	2360
2450	49	3	4	13 0	21 3	9 5	25 6	5,360	15,950	39	2400
2520	51	3	4	13 6	21 9	9 5	26 0	5,520	16,100	40	2440
2700	52	3	4	14 6	22 9	9 5	26 3	5,900	16,400	41	2570
2970	55	3	5	12 6	20 9	11 0	25 0	6,200	17,100	45	2760
3050	61	3	5	13 0	21 3	11 0	25 6	6,360	17,250	46	2830
3185	64	3	5	13 6	21 9	11 0	26 0	6,520	17,400	47	2900
3450	67	3	5	14 6	22 9	11 0	26 6	6,830	17,900	48	2950
3500	70	3	6	12 6	20 9	12 7	24 6	7,150	18,200	51	3100
3650	73	3	6	13 0	21 3	12 7	25 0	7,280	19,100	51½	3120
3780	76	3	6	13 6	21 9	12 7	25 6	7,400	20,000	52	3140
4050	79	3	6	14 6	22 9	12 7	25 6	7,620	21,500	53	3200
4125	83	3	7	12 6	20 9	14 2	25 6	7,800	22,300	60	3630
4250	85	3	7	13 0	21 3	14 2	26 0	8,000	22,600	61	3660
4400	88	3	7	13 6	21 9	14 2	26 0	8,225	22,900	61½	3780
4750	89	3	7	14 6	22 9	14 2	26 0	8,720	23,400	62	3790
4750	92	3	8	12 6	20 9	15 9	24 6	9,000	23,800	67	4000
4900	97	3	8	13 0	21 3	15 9	25 0	9,550	24,150	68	4060
5040	101	3	8	13 6	21 9	15 9	25 6	10,000	24,500	68½	4150
5400	105	3	8	1[illegible] 6	22 9	15 9	26 0	10,800	25,200	69	4200

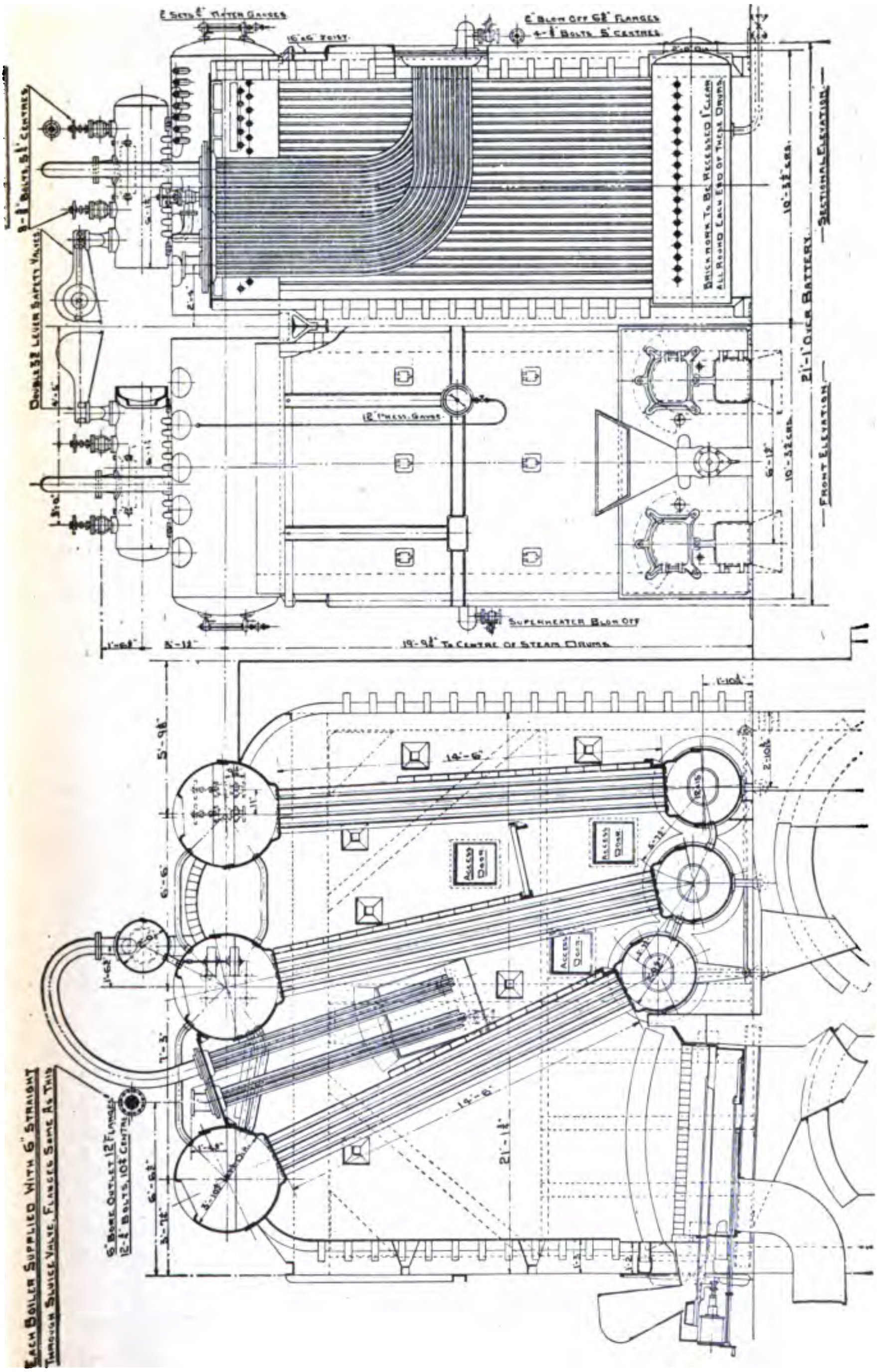


FIG. 129.—Arrangement of two Clarke-Chapman boilers.

Fig. 129 shows the arrangement of two "Woodeson" boilers, of which ten are at present working at Naples. These boilers are fitted with superheaters forming an integral part of the boiler.

The following is the results of a test of one of these boilers :—

Date of test	13th October, 1916.
Duration	9 hours.
Heating surface	3440 sq. ft.
Grate area	76 ,,
Boiler pressure	186 lbs.
Feed water temperature	156° Fah.
Total temperature of steam	546° ,,
Flue gases temperature	475° ,,
,, gas CO_2	10·6 per cent.
Total water evaporated	103,923 lbs.
Water evaporated per hour	11,547 ,,
Total coal burnt	11,564 ,,
Coal burnt per hour	1285 ,,
Water evaporated per 1 lb. of coal fired	9·17 ,,
,, ,, from and at 212° Fah.	11·08 ,,
Coal burnt per sq. foot of grate	16·6 ,,
Water evaporated per sq. foot of heating surface	3·35 ,,
,, ,, from and at 212° Fah.	4·05 ,,
Class of firing	Dusseldorf stokers.
Calorific value of coal	13,050 B.T.U.
Draught at back of boiler	0·5 in. pressure.
Efficiency of boiler	81·0 per cent.
,, ,, and economiser	85·3 ,,

Fig. 130 shows a standard Woodeson water-tube boiler with chain grate stoker and superheater, with the general arrangement as fitted in boiler-house.

Figs. 131 and 132 illustrate a boiler-house and turbine-room of a power station in Lancashire. The boiler heating surface is 5400 sq. feet, and it is capable of evaporating 25,000 lbs. of water per hour. The working pressure is 200 lbs. per sq. inch.

Thornycroft Boiler.

Fig. 133 illustrates an improved and modified type of Thornycroft's "Daring" boiler, and is really a larger and improved type of the "Speedy" boiler. The room occupied is less, power for power, and the two furnaces and large fire-grate area render it more suitable for working at moderate rates of fuel consumption. The boiler illustrated has a total tube surface of 6000 sq. feet, grate area 63 sq. feet, and the working pressure is 230 lbs. per sq. inch.

On the smaller boilers a grate is situated on each side of the

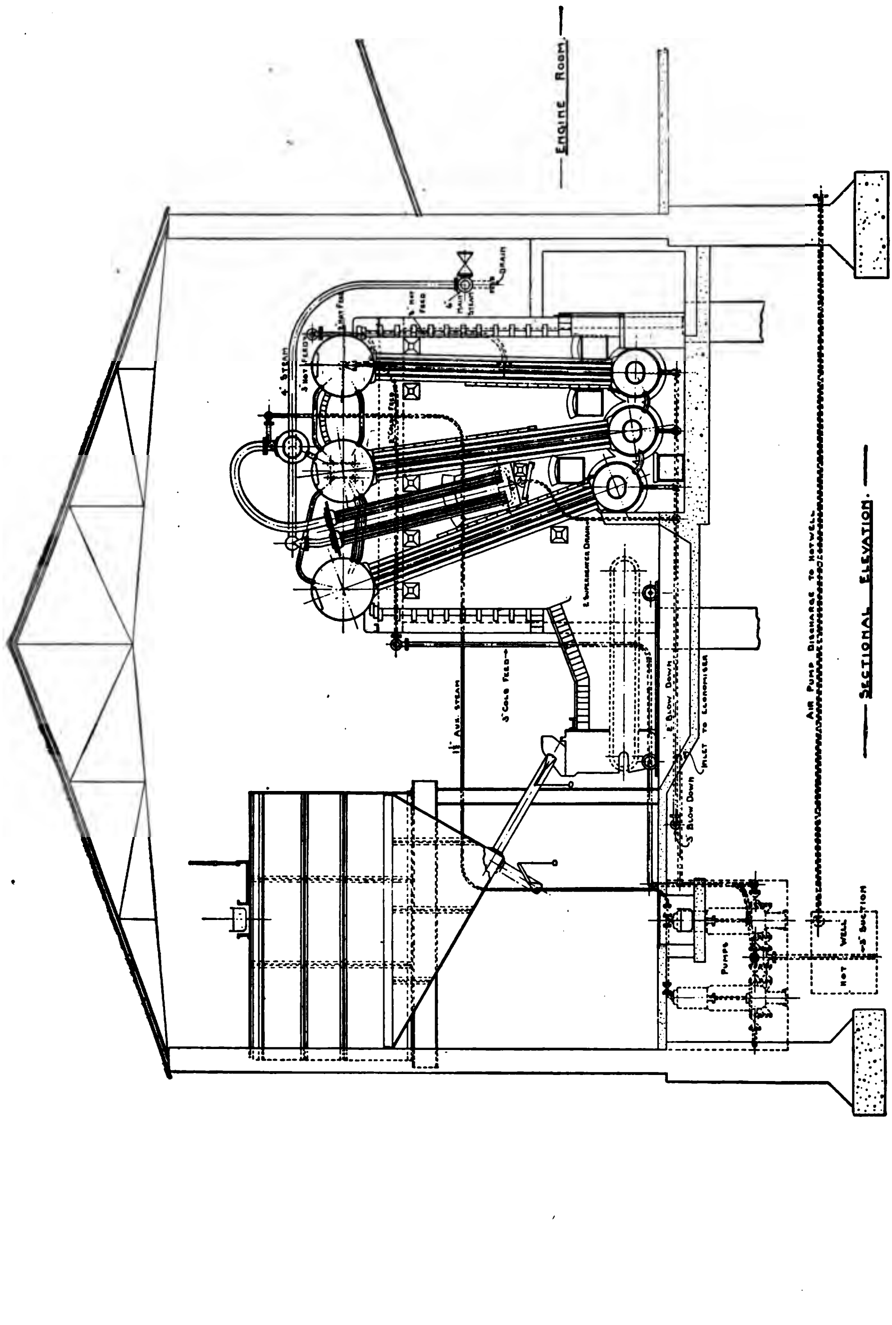


FIG. 130.—Clarke-Chapman boilers.

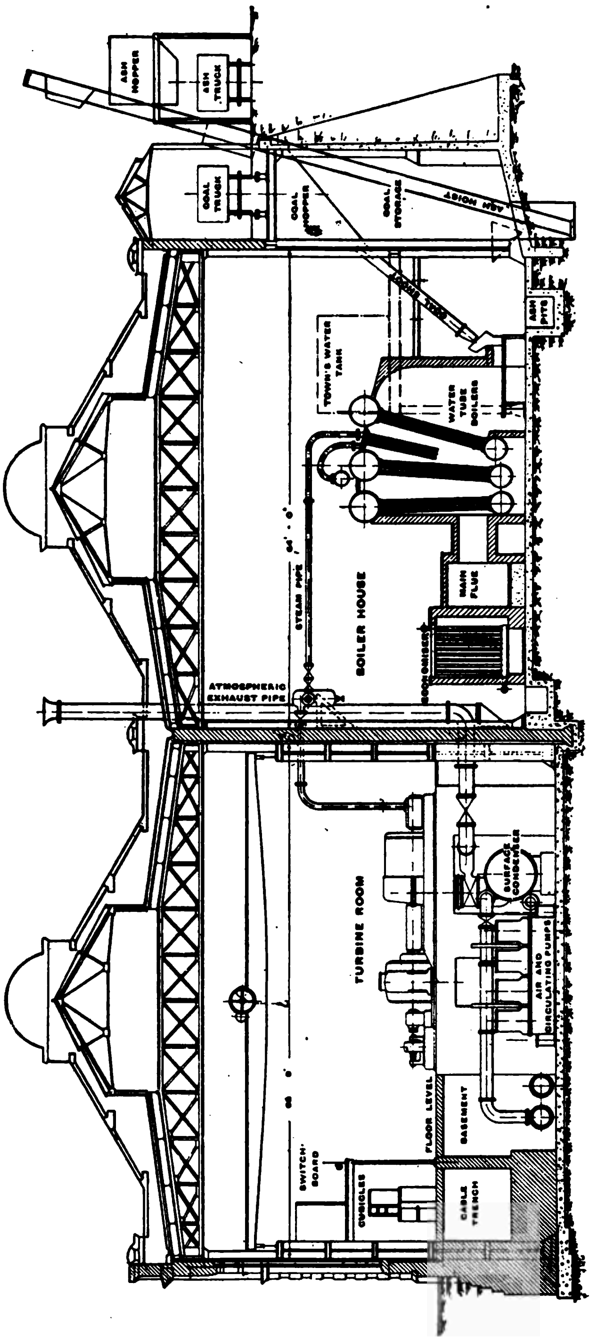


FIG. 131.—Vertical section of power-house with Clarke-Chapman boilers.

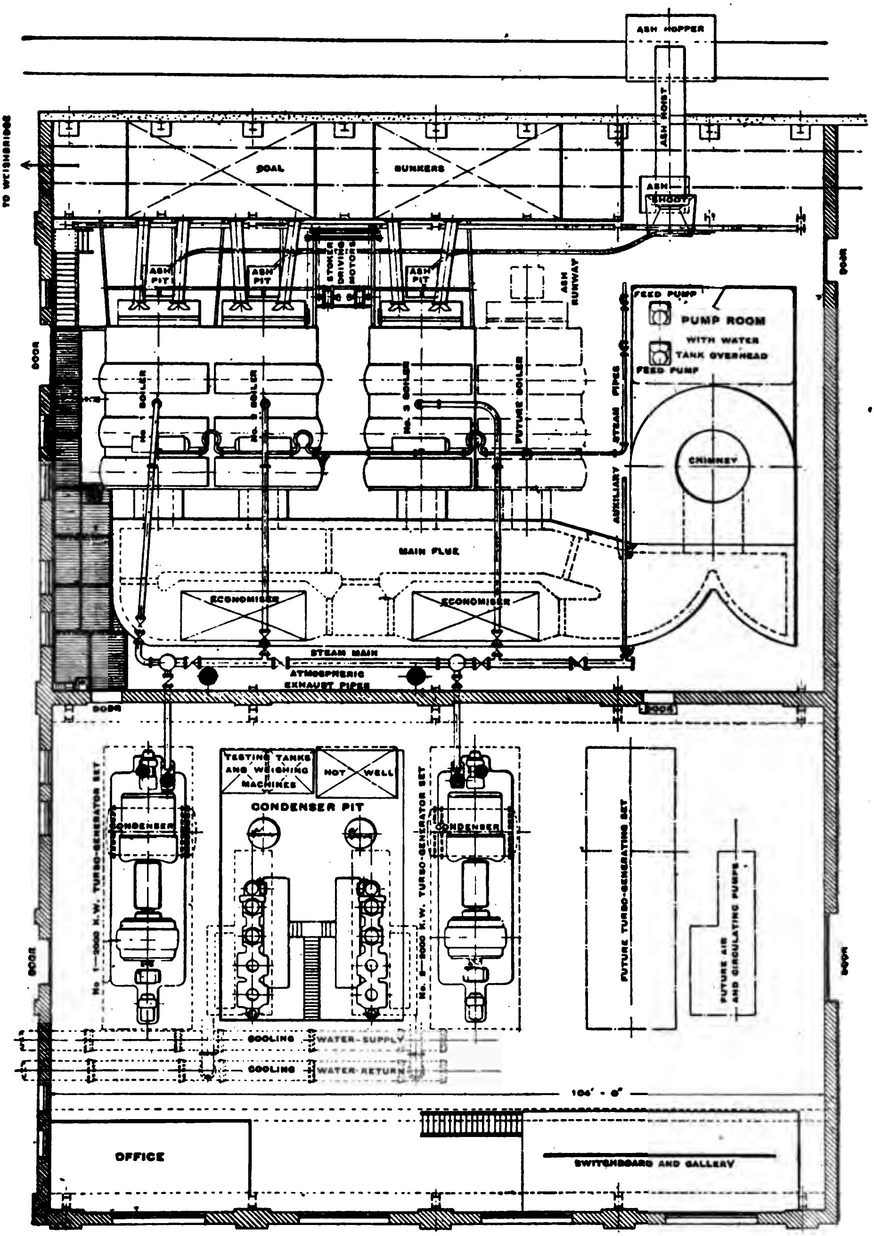


FIG. 132.—Plan of power-station showing general arrangements of boilers and turbo-generators.

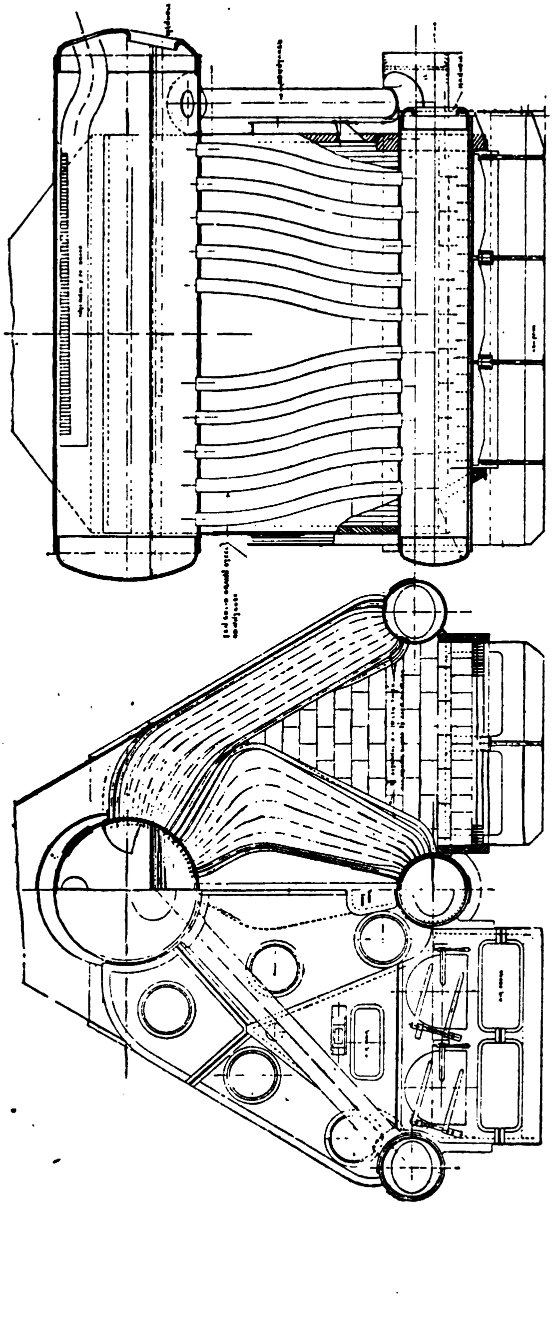


FIG. 133.—Improved "Daring" type of Thornycroft boiler.

central drum. The flames enter the inner nest of tubes at the bottom along the whole length of the grate, and pass out at the top along the whole length of the nest of tubes. On the outer side of each grate the combustion chamber is bounded by a double row of tubes, which are bent together so as to form a single continuous wall; these tubes open at their lower end into a lower drum of small diameter, which is connected through a pipe to a central lower drum.

The feed water, which enters at the upper drum, passes down into the central lower drum, through a row of tubes in the middle, between the two inner nests of small tubes. All tubes except the last named discharge into the steam space above the water level in the upper drum.

In the larger size boilers, as shown in the illustration, three drums are used at the bottom; the centre of these drums is connected with the large upper drum by two nests of tubes, and the two outer drums are connected by a single nest of tubes each. At either end of the upper drum, a large down-comer pipe leads to each of the two outer lower drums, while the centre one is connected to the upper drum from end to end by a row of slightly curved down-comer pipes. As none of these pipes is exposed to the heat of the furnace, they are able to carry down the water from the upper drum to the lower part of the boiler. Between the lower drums are the two fire grates, and the two outermost rows of each set of tubes are bent so as to form tube-wall rows, with openings at the bottom on the fire-side rows, and at the upper ends on the rows nearest the uptake. To make these tubes touch each other, their diameter is increased to about 1⅜ inch, whereas the diameter of the other tubes is only 1⅛ inch. The flames can only penetrate the nest of tubes at the bottom, where they do not touch each other, and pass out of the top of the "tube wall" where the tubes enter the upper drum. The type of boiler shown is designed to give 1750 indicated horse-power.

A modified type of Thornycroft's "Speedy" boiler is shown in Fig. 134. This boiler was designed to overcome the trouble experienced with corroded tubes. In the earlier types of "Speedy" and "Daring" boilers, it was found that when the boilers were lying idle, the unsubmerged tube surfaces were exposed to the corrosive action of the atmosphere. With the modified type of boiler shown in the illustration, the tubes are fully submerged.

Marshall's Water-tube Boiler.

This boiler is of a very simple type, and consists of a steel drum with a steel header or water leg at each end for carrying the tubes, riveted direct to the drum. The standard sizes range from 50 to 250 effective horse-power. The sizes of 200 horse-power upwards have two drums. The ends of the drums are flanged, and of a special thickness and design, suitable for receiving the mountings without the use of intermediate stools or fixings.

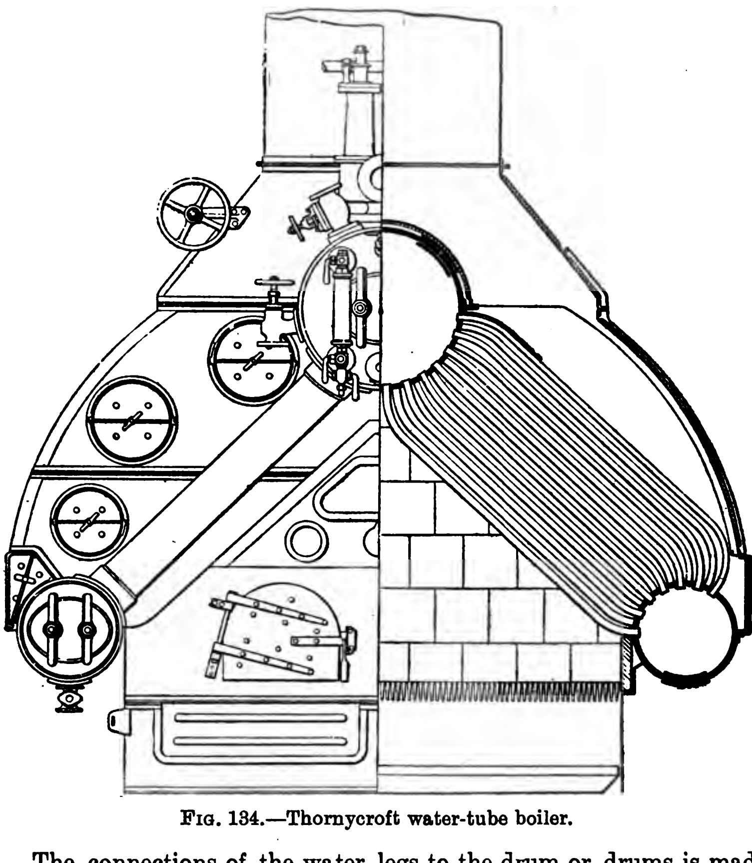


FIG. 134.—Thornycroft water-tube boiler.

The connections of the water legs to the drum or drums is made with ample waterway, so as to provide for thorough circulation. Plates are provided round these waterways to give additional strength and so enable them to withstand a high working pressure. The headers afford a large cross-sectional area of steam and waterway, so that the boiler will stand forcing without the possibility of the tubes being bared.

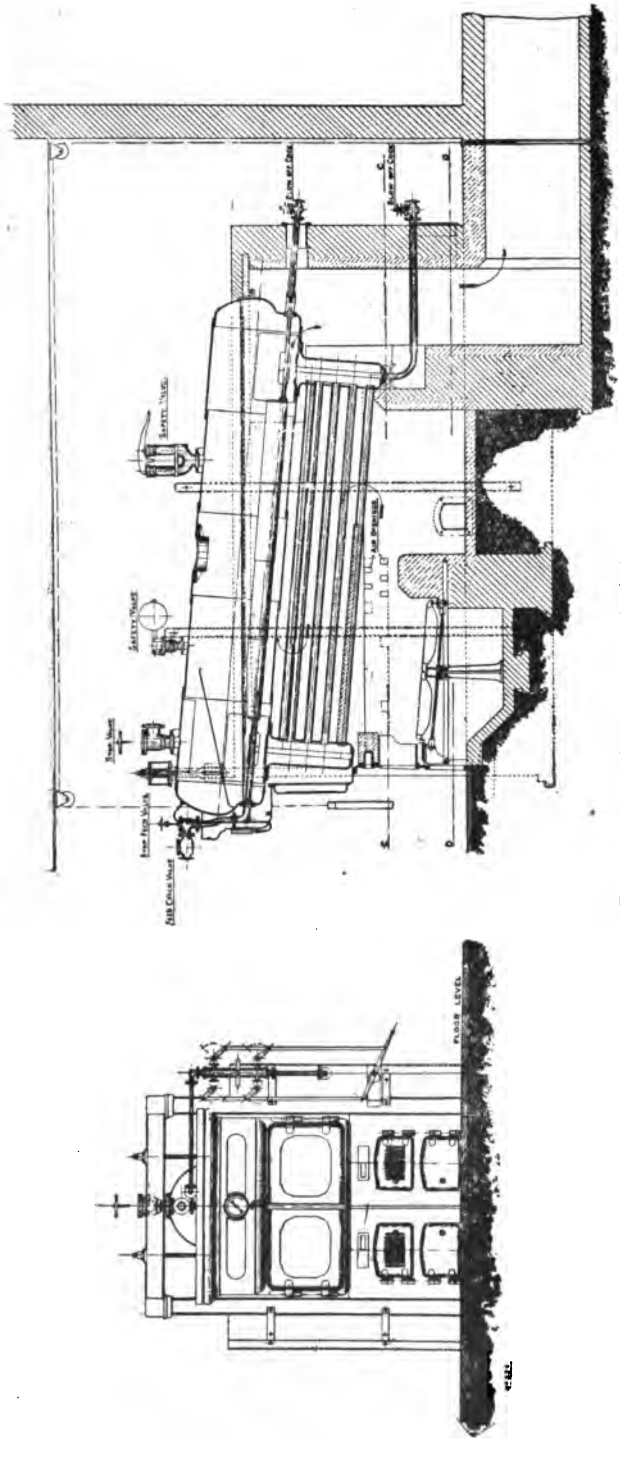


FIG. 135.—Marshall's water-tube boiler.

A series of straight solid drawn steel tubes connect the water legs. The tubes are expanded into holes in headers, the holes being slightly larger in diameter than the tubes, and the headers are fitted with lids opposite each tube end; by this arrangement the removal and replacement of a tube can be readily done when necessary. The open-

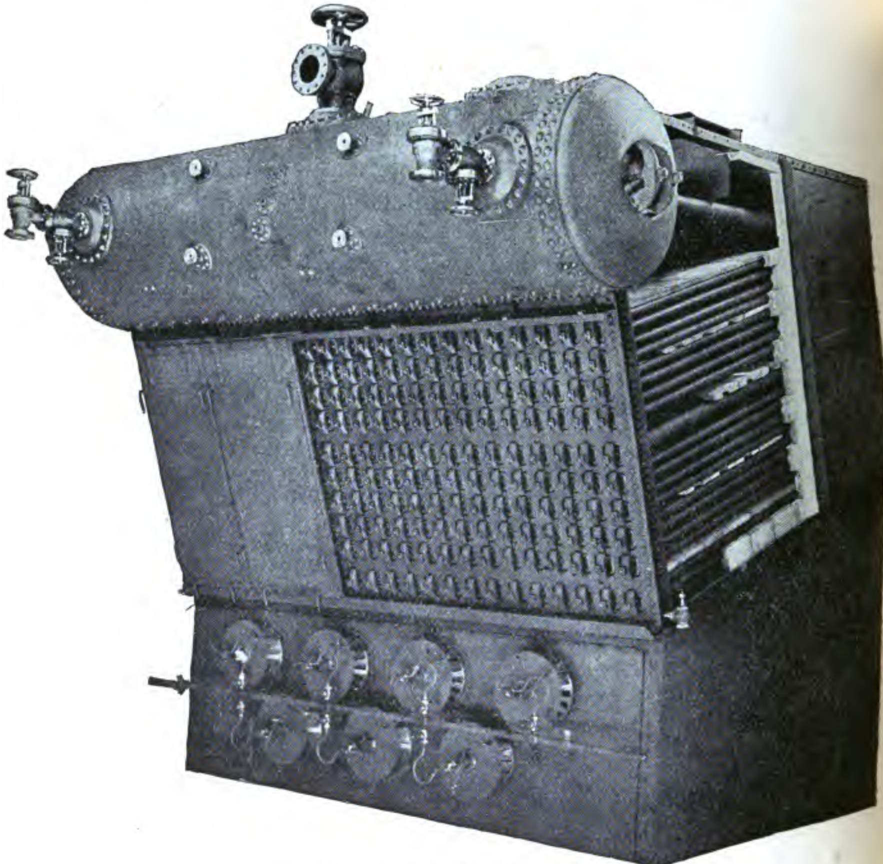


FIG. 136.—Ward water-tube boiler.

ings in the front plates afford complete facility for cleaning the tubes and the interior of the water legs.

The front and back plates of the water legs are tied together by hollow steel screwed stays, and when the boiler is set in the brickwork a steam jet pipe can be passed through the stays, to blow the soot off the exterior of the tubes. The tubes are parallel with the drums, and the boiler is set with an incline to the back end.

These boilers are specially adapted for burning wood, saw-mill refuse, and other kinds of inferior fuel, as the grate areas are large. The working pressure is 150 lbs. per sq. inch. The boiler with its brickwork setting is shown in Fig. 135. They are also constructed with wrought-iron brackets to carry the boiler on side wall settings, or with slinging tackle to support the boiler from cross girders.

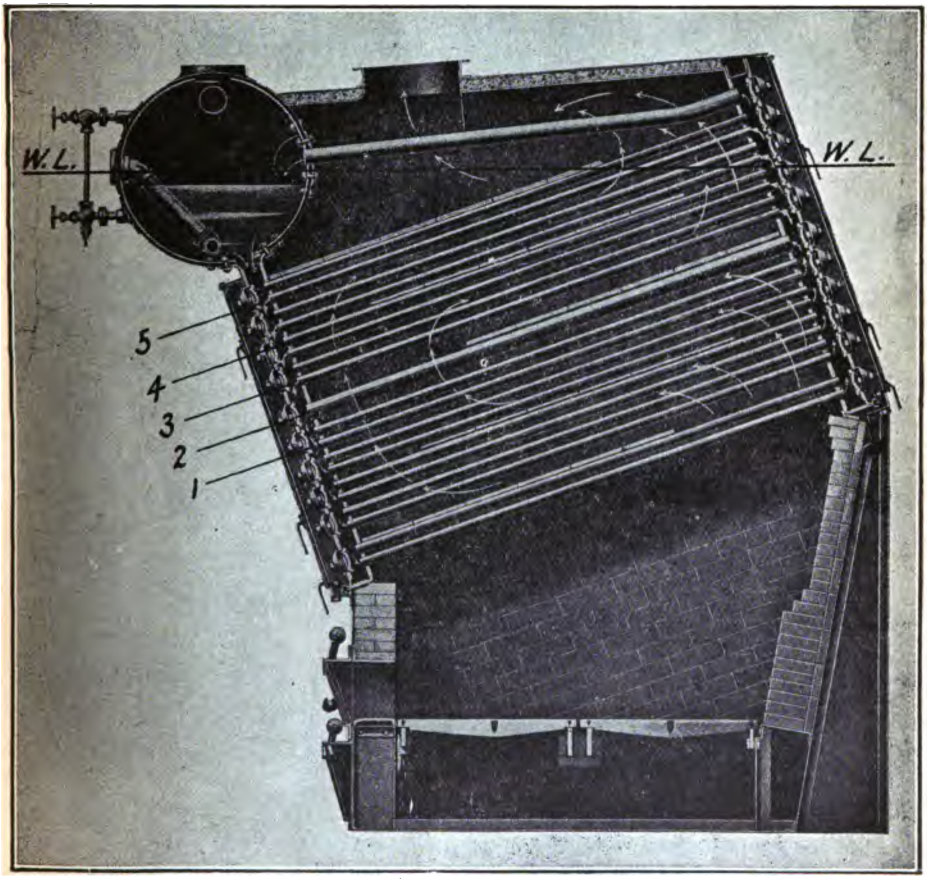


FIG. 137.—Sectional view water-tube test boiler.

The Ward Boiler.

The Ward boiler is constructed by the Charles Ward Engineering Works, Charlestown, W. Va., U.S.A., and Figs. 136 and 137 show a boiler having a tube-heating surface of 4405 sq. feet, and a furnace volume of 476 cub. feet. The construction of the various parts is

FIG. 138.—View of steam drum.

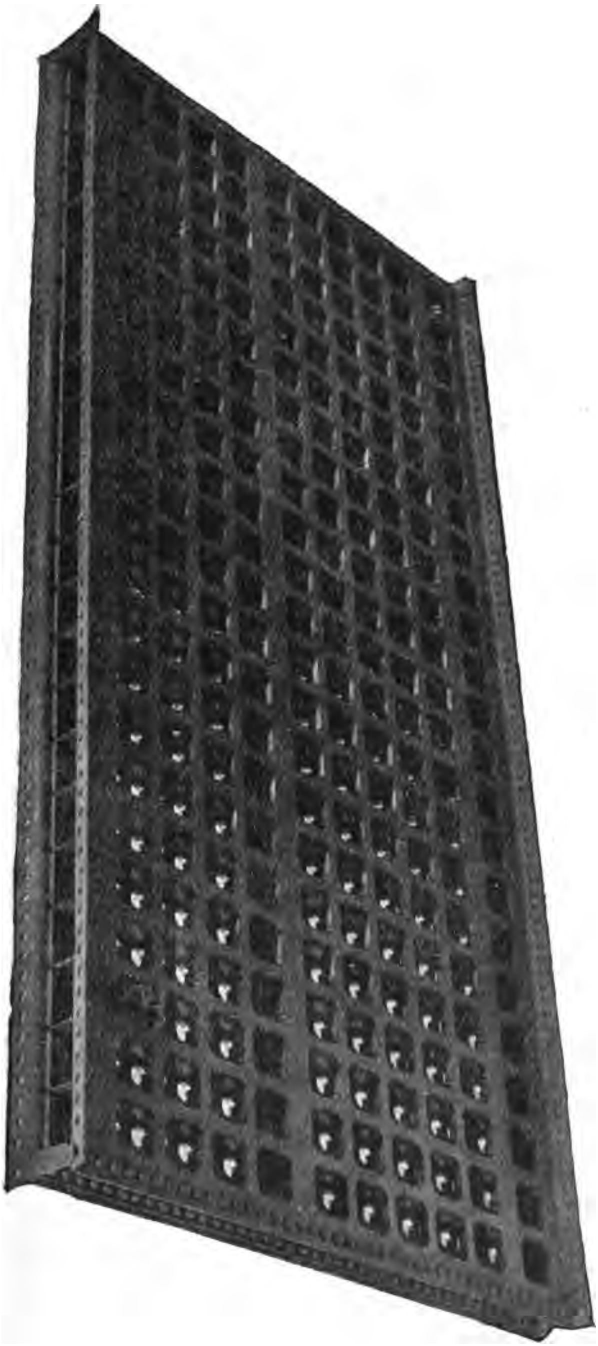


FIG. 139.—Front flitch, or header.

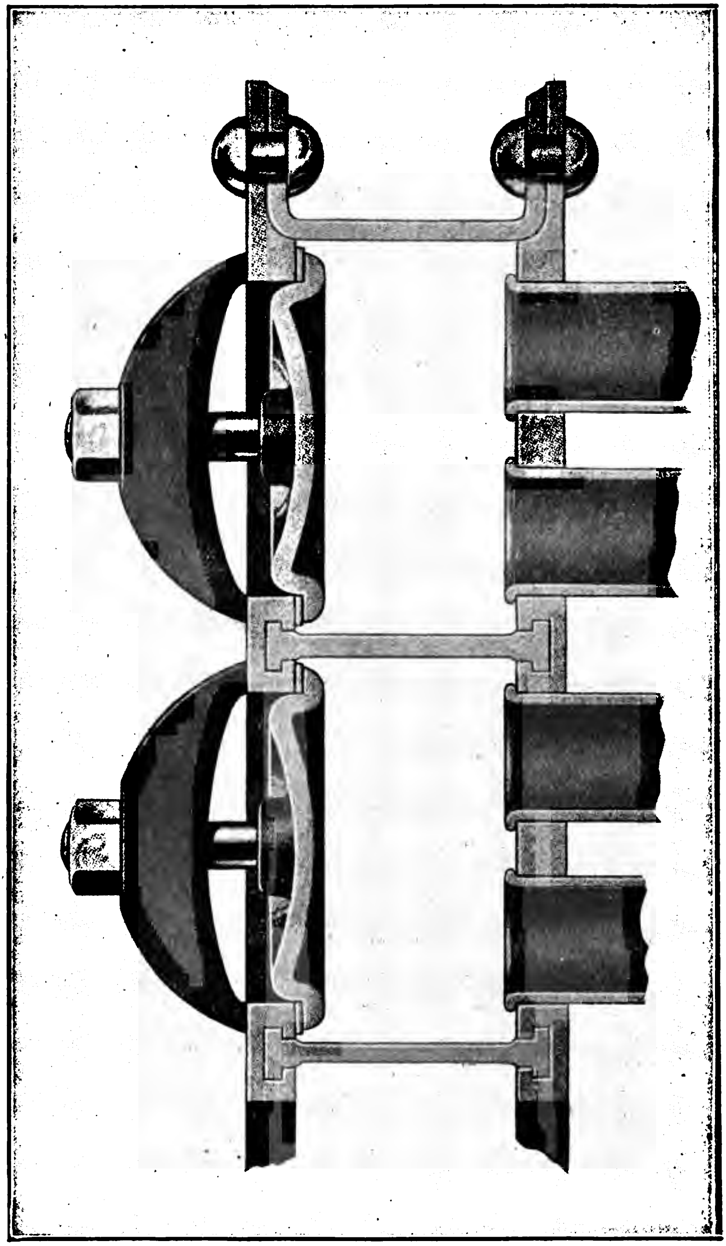


FIG. 140.—Section through header, showing method of staying tube and hand-hole sheets.

shown in the illustrations. Fig. 138 is the steam drum, Fig. 139 the front flitch or header, Fig. 140 shows a section through the wrought-steel header with method of staying the tube and hand-hole sheets, and Fig. 141 gives a section showing the header construction.

In a recent test, the boiler was fitted with a wooden air-box at the front, provided with an air-lock. Air was supplied by means of a motor-driven blower of constant speed type, and the air supply was

FIG. 141.—Section showing header construction.

regulated by means of a butterfly shutter in the blower discharge, and a sliding door on front of air-box.

Feed was supplied by means of two horizontal plunger pumps discharging through two feed-water heaters.

Oil was delivered by two pumps, discharging through an oil-fuel heater to the fuel-oil main at boiler front, a special air chamber being fitted on the discharge line. There were fitted in addition three large air chambers near the oil heater to reduce fluctuations in pressure. The oil used was Elk Refining Co. paraffin-base West Virginia oil, of the following characteristics :—

Specific gravity	0·8245
Baumé degrees	40·1
Flash-point Fah.	144°
Fire-point Fah.	270°
Viscosity at 60° Fah. (Engler)	9·25
B.T.U. per lb.	18,879

Three tests were made, the first test to determine the efficiency of the boiler when burning oil at the rate of 2300 lbs. of oil per hour, the second when burning oil at the rate of 1500 lbs. of oil per hour, and the third test when burning at the rate of 3100 lbs. of oil per hour.

Test No. 1 was at the approximate rate of 2300 lbs. of oil per hour and lasted for six hours. Seven burners fitted with $\frac{5}{64}$-inch tips and $\frac{3}{64}$-inch plugs were used.

Two oil pumps, two feed pumps, and two feed heaters were in operation throughout the test.

There was some vibration on several occasions during the trial due to lack of care with air regulation.

There was no observable smoke during the entire trial, and a small excess of air was supplied.

The casing of the boiler, especially the left side in wake of lower rows of tubes at the back, became red-hot in places, indicating insufficient lagging.

Test No. 2.—Approximately 1500 lbs. of oil was consumed per hour, and the test was for six hours. Seven burners were used having $\frac{1}{16}$-inch tips and $\frac{3}{64}$-inch plugs.

One oil pump, one feed pump, and one feed heater were in operation. The conditions were very steady during the entire trial. The casing became quite hot at sides near back of boiler.

There was no observable smoke during the run.

At the end of the test the boiler was let down; the brickwork appeared in a very good condition; the bottom appeared somewhat uneven, indicating that magnesia under the bricks was disintegrating to some extent.

Test No. 3.—Before making this test additional asbestos millboard was placed behind the metal side casing, and the brickwork, especially on the left side of the boiler, was repaired.

The test was for six hours, but on account of insufficient time to get the boiler warmed up to proper conditions, it was decided to use data for four hours only.

Seven burners having $\frac{3}{32}$-inch tips and $\frac{3}{64}$-inch plugs, and two oil pumps, two feed pumps and two feed heaters were used. Owing to the lightness of the oil, difficulty in forcing a sufficient amount

through the burners was experienced when the oil was heated, and therefore the oil was not heated after the first hour; with cold air 3100 lbs. of oil per hour could be burned. No smoke was visible during the entire run.

The left side of the casing became red-hot during test, indicating an insufficient insulation in the casing as built.

SYNOPSIS OF TESTS.

Test No.	2.	1.	3.
Approximate rate of oil burned per hour	1500	2300	3100
Oil actually burned, lbs. per hour	1509	2440	3082
Lbs. of water evaporated from and at 212° 1 ah. with oil as fired of 19,879 B.T.U.	16·73	16·48	16·21
Reduced to 19,000 B.T.U.	15·99	15·75	15·49

To test the circulation, small propellers were placed in two of the intermediate 4-inch tubes, with a rod running through the hand-hole. The movement of the rods indicated a down-flow at all rates of steaming.

After the tests, propellers were installed in several of the 2-inch tubes to ascertain the character of the circulation. These tubes are shown in Fig. 136. The results were as follows: No. 2 began to revolve in about five minutes after the fires were started, the direction of rotation showing down-flow in these tubes. No. 1 hesitated slightly, showing some inclination to turn left-handed, which was probably due to the suction caused by the down-flowing water from No. 2. This condition changed before steam was raised, and No. 1 began to revolve in the opposite direction, showing that the water was flowing up the lower bank of 2-inch tubes. Nos. 3 and 4 began to revolve left-handed in about ten minutes after the fires were lighted, the speed increasing so much that the revolutions could not be counted; the direction of rotation showed down-flow in these tubes. No. 5 remained stationary until there was about 50 lbs. of steam in the boiler, and then it commenced to revolve in a left-handed direction, indicating that as soon as the water level was raised on the high side of the tubes, due to the steam-making condition, there was a down-flow through the 2-inch tube mentioned.

From these experiments it is inferred that the flow is upward through all the 2-inch tubes below the middle baffle, and downwards through all the 2-inch tubes in the upper portion of the boiler, the velocity being very high, for, as stated, the propellers were revolving

in the neighbourhood of 200 revolutions per minute. The high velocity of the propellers in the small tubes is due to the fact that the shafts were of very small diameter and consequently there was very little friction in the apparatus.

To establish the volume of water flowing down through the 4-inch tube, one of the propellers was removed and installed in a short piece of pipe, this being connected to the water main, and the propeller operated under a pressure of about 40 lbs., the discharge being throttled until the propeller made approximately the same number of revolutions as it did in one boiler. Readings from the water meter over a period of five minutes showed that there was about 50 gallons per minute passing through this tube. This, however, is only an indication of the amount of water flowing through the 4-inch tubes, as the friction on the propellers was very much greater under the higher pressure conditions existing in the boiler.

The foregoing results throw a new light upon the problems of circulation in boilers of this general type of construction. They also indicate that the baffling as arranged secures the benefit of the counter-current principle throughout the boiler.

No distortion of any of the lower tubes was observed, and it is apparent that there is no difficulty in giving the lower tubes an ample supply of water.

TABULATED RESULTS OF TESTS.

Test No.	2.	1.	3.
Barometer ht. in inches	30·79	30·73	30·55
Steam pressure in lbs. by gauge	194·5	196	197·5
Feed temperature, Fah.	183°	113°	168°
Oil pressure at burners, lbs.	258°	255°	283°
,, temperature at burners, Fah.	163°	141°	50·5°
Draught pressure, inches of water	2·34	4·91	4·96
Stack temperature, Fah.	418°	475°	520°
Carbon dioxide percentage in flues	12·48	12·61	13·14
Moisture in steam, fraction of 1 per cent.	·616	·606	·69
Lbs. of water evaporated per lb. of oil	15·59	14·37	14·89
Water evaporated per sq. foot of heating surface per hour	5·34	7·96	10·41
Water evaporated per sq. foot of heating surface from and at 212° F.	5·73	9·13	11·34
Lbs. of oil burned per sq. foot of heating surface per hour	·3427	·5541	·6996
Lbs. of oil burned per cub. foot of furnace per hour	3·17	5·125	6·475
Boiler efficiency, per cent.	81·63	80·45	79·13

The Yarrow Boiler.

Fig. 142 shows the details of the Yarrow water-tube boiler. It consists, as will be seen, of an upper steam and water drum and

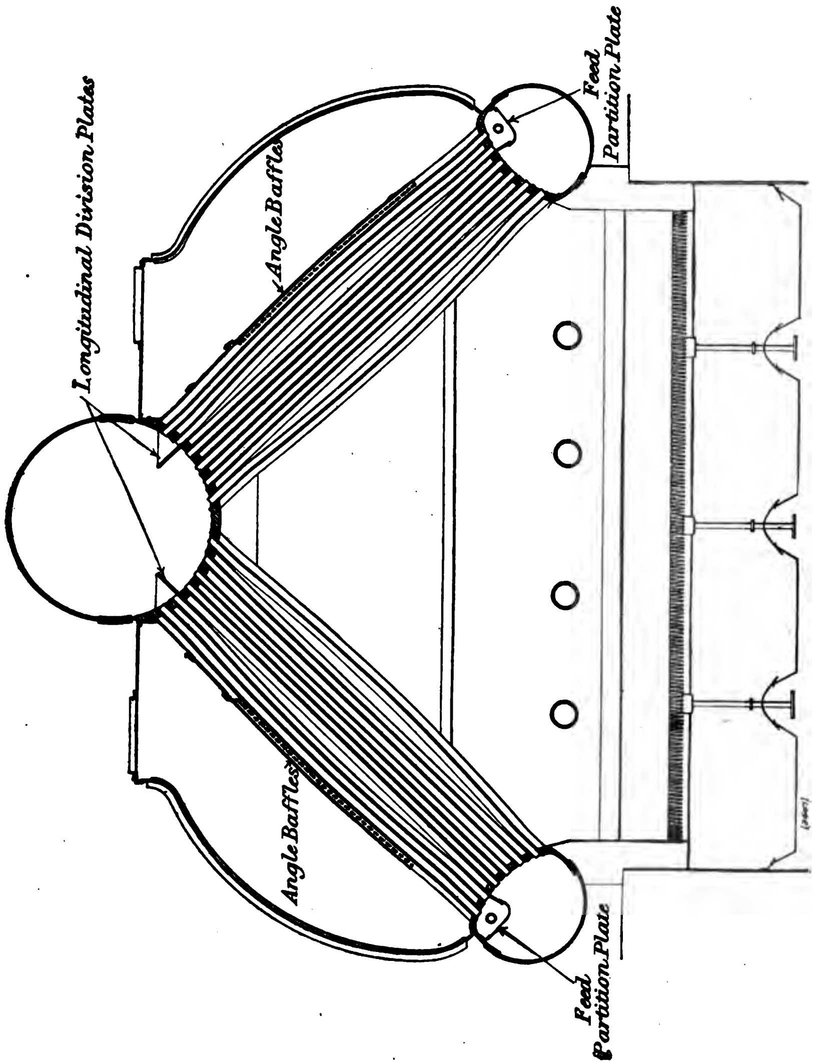


FIG. 142.—Yarrow water-tube boiler.

two lower water drums, connected by perfectly straight tubes. The bottom ends of the tubes are expanded into a tube plate which forms the top part of the water chamber.

The tubes are made from solid drawn steel. It will be noticed that angle-iron baffles are placed on the outside row of tubes; this is done to distribute the furnace gases uniformly over the boiler tubes. These baffles lie on the tubes in such a manner as partially to close up the space between two adjacent tubes, and thus set up a slightly varying resistance to the flow of gases. By arranging these baffles suitably with reference to the uptake, the gases can be directed by means of the slightly varying resistance so that the gases pass approximately uniformly through the nest of tubes. These baffles are simply hung on projecting studs, and are easily removed when required for cleaning or for any other purpose. It has been found possible by means of these baffles practically to equalise the temperature of the gases as they pass the last row of tubes of the tube nest, thus securing a high efficiency.

The old system of feed heating in this type of boiler consisted in dividing off a certain number of the outer rows of tubes by partitions in the water pockets, and passing the feed into the space thus divided off, so that the feed water passed up two or three rows of tubes before it mixed with the general circulation of the boiler. This method of feed heating has been found to result in a considerable economy, but experience disclosed that with the higher rates of evaporation now required, the cold water which passed up these feed-heating tubes, after entering the upper drum, short circuited and descended the adjoining rows of tubes, and did not mix with the water in the upper drum as required. The result of this short circuiting was alternately to heat and cool the plates and the joints of the water pockets, producing strains, and developing ultimately in some cases serious leakage. By fitting a longitudinal plate on each side of the steam chest, as shown in the illustrations, it was found possible to prevent this short circuiting, and this plan is adopted in all the later types of boilers.

In the boiler illustrated a very high efficiency was obtained on the trials which were conducted at the works of Messrs. Yarrow. The following results were obtained on trials extending over twenty-four hours, with the boiler burning $\frac{1}{4}$ lb. of oil per hour per sq. foot of heating surface.

The trials were undertaken in order to test the boiler and the conditions which would prevail when cruising at a low power, and to ascertain the evaporation when the feed-water heating arrangements were in use, and alternately when the feed was passed direct into the top drum, as was formerly the practice. The twenty-four hour trial was divided into periods of four hours, and the feed water

was passed for each four hours alternately into the feed-heating tubes and the top drum.

Results of Trials burning 0·25 lb. of oil per sq. foot :—

	Feeding into Feed Heater.		Feeding into Top Drum.	
	Water from and at 212° Fah.	Temperature of Uptake.	Water from and at 212° Fah.	Temperature of Uptake.
		Deg. Fah.		Deg. Fah.
First four hours .	16·49	290	—	—
Second ,, ,, .	—	—	15·81	407
Third ,, ,, .	17·08	325	—	—
Fourth ,, ,, .	—	—	15·78	427
Fifth ,, ,, .	16·85	347	—	—
Sixth ,, ,, .	—	—	15·89	435
Mean results .	16·8	321	15·83	423

The results given above show that when feeding into the top drum the evaporation was 15·83 lbs. of water from and at 212° Fah. per lb. of oil consumed, the funnel temperature being 423° Fah. When feeding into the section of the water pockets, to which the feed-heating tubes are attached, 16·8 lbs. of water were evaporated per lb. of oil, and the temperature of the funnel gases was 321° Fah. The gain under these circumstances by adopting this special system of feed heating was an increase in evaporation per lb. of oil of 0·97 lb., or 6 per cent., and also a reduction in the temperature of the funnel gases of 102° Fah.

The following figures give the results of two further trials, of fifteen hours' duration, one when burning coal at the rate of 28 lbs. per hour per sq. foot of grate surface, and the other when burning 17 lbs. The first is shown in line A and the second in line B.

Nature of Trial		Lbs. of Coal per Sq. Foot of Grate.	Lbs. of Coal per Sq. Foot of Hea ing Surface.	Lbs. of Water Evaporated per lb. of Fuel.	Lbs. of Water Evaporated per Sq. Foot of Heating Surface.	Temperature of Uptake.
						Deg. Fah.
Official thirty hours .	A	28	0·59	10·96	6·48	622
Coal-burning trial .	B	17	0·36	13·60	4·93	491

The consumption obtained with the most improved type of Yarrow boiler in combination with the latest type of turbine is so satisfactory that 1 shaft horse-power can be obtained from 0·9 lb. of

oil fuel; and, if superheating be adopted on the Yarrow system, a gain of 10 per cent. for every 100° Fah. is secured. From the experiments made by Messrs. Yarrow, this amount of superheat is easily obtainable in marine practice, and it is not unreasonable to expect that with 200° Fah. of superheat it will be possible to obtain 1 shaft horse-power from 0·75 lb. of oil fuel under naval conditions, which are more severe than those prevailing in the merchant service.

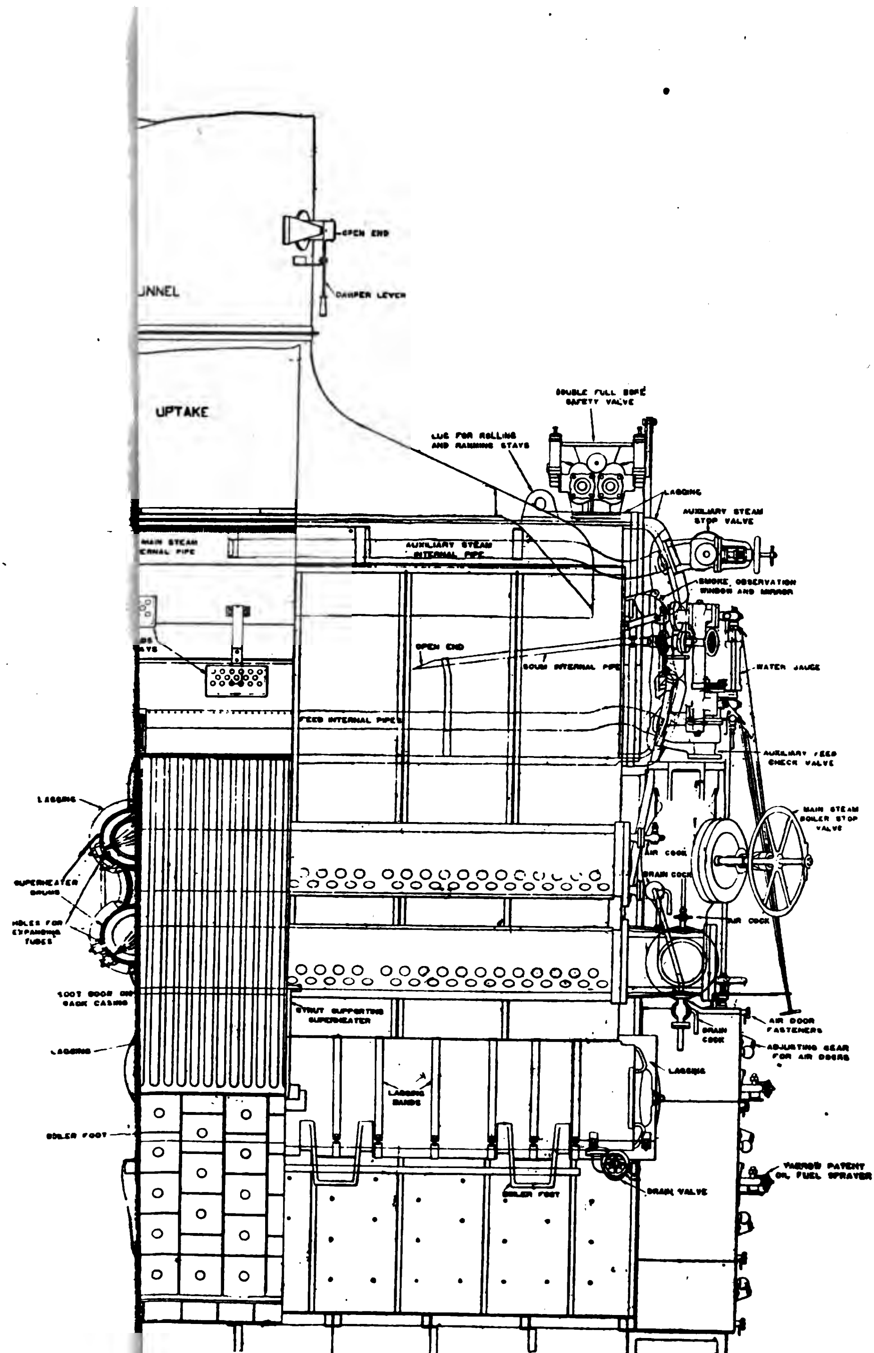
Yarrow Boiler with Superheater.

The latest type of Yarrow boiler is shown in Plate V. The boiler with its superheater consists of a top steam collector and two lower water pockets. On the left-hand side of the boiler there are fewer rows of generator tubes, and on this side the superheater is fitted, thus the resistance to the gases is approximately equal on both sides.

The total heating surface of the unit is 6700 sq. feet, of which 1265 sq. feet is superheating surface; the actual heating surface on the superheater side of the boiler is 3453 sq. feet, and on the other side 3247 sq. feet.

The superheater consists of a number of U tubes expanded into two longitudinal collectors, small doors being fitted so that access can be obtained to the tubes when required. The leading feature of this arrangement is that the superheater is placed on one side of the boiler only, and a damper is fitted in the uptake on the same side, as shown in the drawing. If this damper is closed, the whole of the gases are deflected towards the opposite side of the boiler, and no heated gases pass the superheater, the object being that when the main engines or turbines are suddenly eased or stopped, or when steam is being raised, the superheater may be shut off so as to prevent the tubes from being damaged, or the steam from being superheated to an excessive extent, owing to there being insufficient circulation of steam. In this manner one of the objections to the use of superheated steam for marine purposes is overcome.

A further advantage of this arrangement is that when the consumption of steam is suddenly reduced or stopped, not only does the damper prevent the superheater tubes from being burnt, but it also greatly diminishes the output of the boiler at the time when a reduced supply of steam is wanted, because only about one-half of the heating surface comes in contact with the hot gases. To avoid the possibility of the damper getting distorted through over-heating, it is provided with a hollow spindle, to which air is admitted, and which passes from thence between two plates of the damper, escaping at the edge, and thus keeping the damper cool. This arrangement of



ION

HALF SIDE ELEVATION

[*To face page* 188.

Modern

damper has proved thoroughly successful under the most searching conditions.

A number of most important trials have been made, one series of the trials with the damper open and one with the damper closed. The following figures (on next page) give particulars of the trials with the damper open and closed. It will be observed that at the maxi-

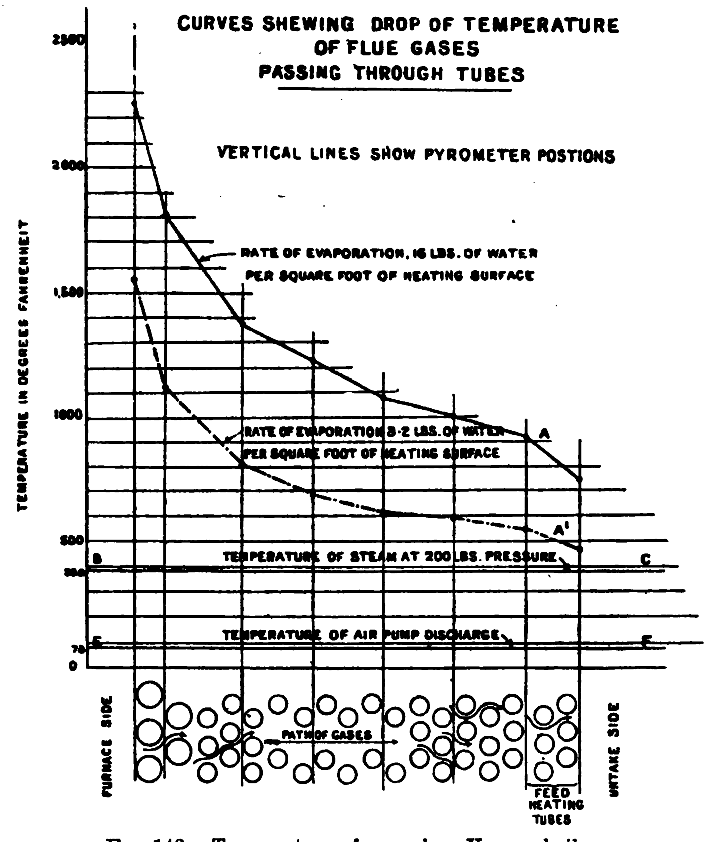


FIG. 143.—Temperature of gases in a Yarrow boiler.

mum rate of evaporation, namely, when burning 1·237 lbs. of oil per sq. foot of heating surface per hour, the degree of superheat was 93° Fah. Corresponding figures are given at lower rates of evaporation.

A large number of experiments have been carried out with this type of boiler, the results of which indicate that it is possible to burn without injury to the boiler 2 lbs. of oil per sq. foot of heating surface per hour. Fig. 143 gives the temperatures of the gases in

YARROW BOILER.—TRIALS WITH DAMPER OPEN. TOTAL HEATING SURFACE, 6700 SQ. FEET.

Steam Pressure, Lbs. per Sq. Inch.	Superheat in Degrees Fah.	Air Pressure, Inches of Water.	Lbs. of Water Evaporated per Hour.	Lbs. of Oil Fuel Burnt per Hour.	From and at 212° Fah.		Lbs. of Oil Fuel Burnt per Sq. Foot of Heating Surface per Hour.	Temperature of Feed Water, Degrees Fah.	Temperature Between Small Nest of Generator Tubes and Superheater, Degrees Fah.	Temperature of Uptake, Degrees Fah.	
					Lbs. of Water Evaporated per Lb. of Oil per Hour.	Lbs. of Water Evaporated per Sq. Foot of Heating Surface per Hour.				Above Superheater.	Above Large Nest of Generator Tubes.
242	93·5	5·0	94,659	8286	14·6	18·0	1·237	58·0	1121	828	887
243	93·0	3·16	76,021	6454	15·0	14·4	·9635	63·5	926	698	727
243·7	82·5	2·44	68,387	5695	15·2	12·9	·850	63·5	903	685	688
242·8	61·1	1·7	46,041	3630	15·9	8·6	·542	64·0	647	536	551
241·8	31·0	·998	20,059	1540	16·1	3·7	·230	62·2	481	432	448
242·2	20·75	·625	8,478	649	16·1	1·55	·096	63·5	465	409	416

YARROW BOILER.—TRIALS WITH DAMPER SHUT. TOTAL HEATING SURFACE, 3247 SQ. FEET.

Steam Pressure, Lbs. per Sq. Inch.	Air Pressure, Inches of Water.	Lbs. of Water Evaporated per Hour.	Lbs. of Oil Fuel Burnt per Hour.	From and at 212° Fah.		Lbs. of Oil Fuel Burnt per Sq. Foot of Heating Surface per Hour.	Temperature of Feed Water, Degrees Fah.	Temperature of Uptakes, Degrees Fah. Above Large Nest of Generator Tubes.
				Lbs. of Water Evaporated per Lb. of Oil per Hour.	Lbs. of Water Evaporated per Sq. Foot of Heating Surface per Hour.			
242·0	4·85	68,648	6287	13·25	25·66	1·936	61·0	913
242·25	3·97	57,693	5065	13·84	21·6	1·56	60·0	843
242·4	2·491	44,050	3504	15·3	16·5	1·09	60·3	673
242·5	1·46	31,481	2473	15·4	11·75	·76	63·5	603

various points in the boiler. The vertical lines correspond to the position of the pyrometers which were placed at various points in the path of the gases. The lower curve indicates the gas temperatures at a rate of evaporation slightly over 3 lbs. per sq. foot of heating surface. The horizontal lines represent temperatures, and the line BC represents the temperature of the steam at 200 lbs. pressure; and the line EF the temperature of the air-pump discharge taken at 78° Fah.

It will be seen that a very great drop in temperature takes place during the passage of the gases through the first row of tubes, showing the large proportion of heat that is taken out of the gases by these tubes. Also it will be observed, that there is a sudden drop in temperature at A and A^1, that is, where the gases pass through the last rows of tubes. This is due to the fact that the cold feed water, which enters a portion of the water pocket, abstracts a greater amount of heat from the gases in ascending the two outside rows of tubes than would be the case if these tubes were full of water at the temperature of the steam.

Reference to Fig. 143 will show that the temperature of the gases at the point A^1, *i.e.* just prior to the gases passing the feed-heating tubes, is about 550° Fah., and the temperature of the steam at 200 lbs. pressure is 388° Fah., a difference of only 162°, whereas the temperature of the air-pump discharge of 78° Fah. gives a difference of 472°. This shows the gain due to this system of feed-heating, and the desirability of extending it, which is effected by having separate water collectors and feed-heating tubes apart from the main water collectors and main generator tubes.

The Babcock & Wilcox Boiler, Marine Type.

The general design of this type of boiler will be seen by reference to Figs. 144 and 145. There are two designs, one having large and medium size tubes, and the other having large tubes throughout, the use of either type depending upon conditions of space, weight, etc.

The boiler is constructed entirely of wrought steel, there being no cast metal exposed to pressure. It consists of a series of inclined tubes which form the bulk of the heating surface; sinuous boxes or headers into which the tubes are expanded; a horizontal steam and water drum; a mud drum; and a furnace of large capacity immediately beneath the inclined tubes. The relative positions of these parts are shown in the illustrations.

The inclined tubes are divided into vertical sections, and, to ensure a continuous circulation in one direction, are placed at an

inclination of 15° to the horizontal. The tubes are so arranged as to break up and ensure efficient contact with the products of combustion.

By distributing the surface into sectional elements, all danger from

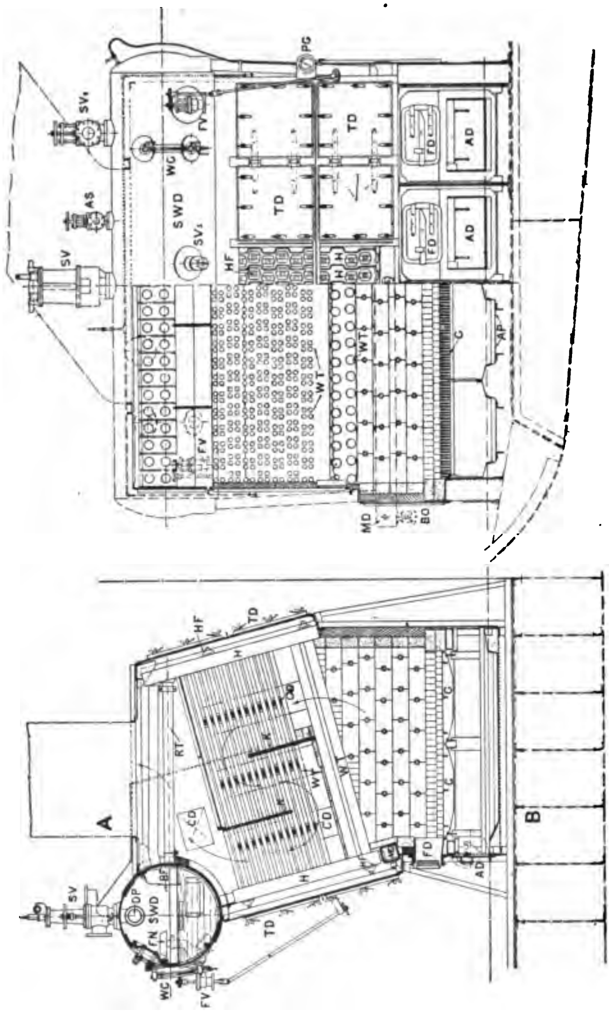


FIG. 144.—Longitudinal section and front elevation of Babcock & Wilcox marine-type boiler.

Index to Parts shown in the Illustrations.

SWD.	Steam and water drum.	TD.	Tube doors.	PG.	Pressure gauge.
WT.	Water tubes.	G.	Grate.	SV_1.	Safety valve.
RT.	Return tubes.	FD.	Fire doors.	SV_2.	Main stop valve.
H.	Headers.	AD.	Ash doors.	SV_3.	Scum valve.
HF.	Hand hole fittings.	AP.	Ash-pan.	AS.	Auxiliary steam valve.
K.	Baffles.	MD.	Mud drum.	FV.	Feed valve.
BF.	Baffle plate.	BO.	Blow-off valve.	FN.	Feed nozzle.
DP.	Dry steam pipe.	WG.	Water gauge.	CD.	Soot cleaning doors.

unequal expansion due to raising steam quickly, or sudden cooling, is overcome. Each section is made up of a series of straight tubes expanded at their ends into sinuous steel boxes known as "headers". The tubes are thus staggered.

Extending across the front of the boiler, and connected to the

upper ends of the front headers by short tubes, is a horizontal steam and water drum of ample dimensions. As the upper ends of the rear headers are also connected to this drum by horizontal tubes, each section is provided with an outlet and inlet for steam and water.

Placed across the bottom of the front headers, and connected thereto by short tubes or nipples, is a forged steel box of square section. This box is situated in the lowest corner of the bank of tubes, and forms a blow-off connection or sediment box through which the boiler can be conveniently drained.

FIG. 145.—Babcock & Wilcox marine-type boiler.

The circulation of water is as follows:—

Heat being applied to the inclined tubes, and vapour formed, the mixture of water and steam rises to the high end and flows through the uptake headers and horizontal return tubes to the steam and water drum, the path of both water and steam being short and direct; the water evaporated in the tubes, and that carried along by the current induced by the steam bubbles, is replaced by water flowing directly from the bottom of the drum downwards through the front headers and into the tubes, part of this water being in turn evaporated.

Upon entering the drum, the steam and circulating water impinge against baffle plates, which cause the water to be thrown downwards while the steam separates and passes round the ends of the baffle

plates to the steam space, from which it is taken by a perforated dry pipe to the stop valve. There is thus a continuous circulation of water in one direction, not hindered by any counter current, and this continuous circulation gives the boiler an equal temperature in all its parts, so that undue strains from unequal temperatures are avoided.

The tubes are of seamless steel. Opposite the end of each tube or group of tubes in the header is an opening or hand-hole through which the tube can be examined, cleaned, or renewed, each opening being closed by a forged steel door and stud. The door is drawn up to its seat by means of a forged steel cap and nut, and the joint made on the inside of the header by an asbestos wire-woven gasket. Should a tube be found defective from any cause, it may be renewed or temporarily plugged, as both ends are accessible.

The placing of the steam and water drum horizontally, with its centre near the water line of the boiler, provides a great body of water where it is needed.

The furnace is either built of ordinary fire-bricks carefully fitted together, or of light fire-tiles, which are bolted to the side plates by a special arrangement. The whole boiler is encased in an arrangement of plating fitted with fire refractory material, which is so effective in preventing radiation of heat that the outside of the casing is cool.

The following figures give the results of the trials of an installation of 18 Babcock & Wilcox boilers on a battleship of 23,000 indicated horse-power. The total tube heating surface was 55,530 sq. feet, and the grate area 1599 sq. feet.

RESULTS OF OFFICIAL TRIALS.

	Low Power.	Maximum Continuous.	Full Power.
Duration of trial	30 hours	30 hours	8 hours
Number of boilers in use	9	18	18
Heating surface, sq. feet	27,765	55,530	55,530
Grate area, sq. feet	799·5	1599	1599
Fuel	Welsh coal	Welsh coal	Welsh coal
Steam pressure, lbs. per sq. inch	220	230	240
Draught, inches of water pressure	·56 in.	·9 in.	1·2 in.
Indicated horse-power	5013	16,930	24,712
Coal, total consumed per hour, lbs.	12,955	28,815	37,315
,, per I.H.P. per hour, lbs.	2·58	1·7	1·51
,, per sq. foot fire-grate surface per hour, lbs.	16·2	18·02	23·33
Heating surface per indicated horse-power	5·54	3·28	2·25

The Babcock & Wilcox Boiler, Land Type.

The land type of Babcock & Wilcox boiler is illustrated in Fig. 146. This boiler is especially suitable for electric generating stations, and quick-steaming plants, where economy of space is of importance.

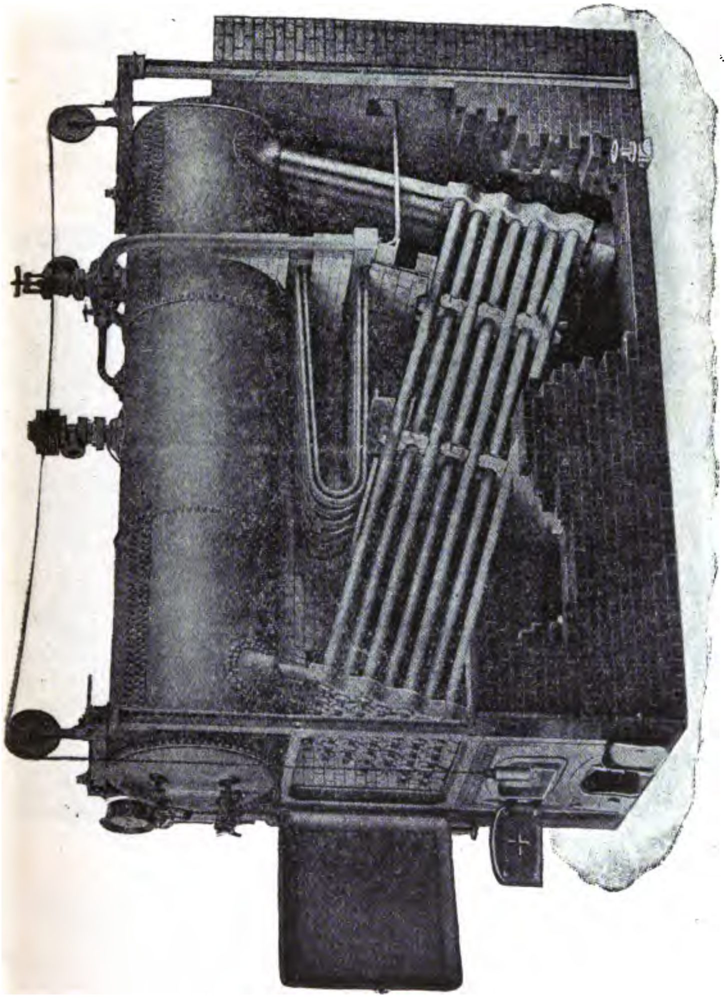


FIG. 146.—Babcock & Wilcox land boiler with integral superheater.

The principal elements in the construction of the boiler consist of three essential parts, each connected with the others, and each of which has a part in the process of steam-raising.

The first of these parts consists of a series of inclined water tubes over the furnace, in which the water, being divided into small volumes,

is quickly raised to a high temperature, and rises through a series of separate connecting boxes or headers, as in Fig. 147, to a horizontal steam and water drum, where the steam separates from the water. The water remaining returns through the vertical tubes at the back into the inclined water tubes, where it is subjected to the action of the fire and again passes into the steam and water drum; thus a continuous and rapid circulation in one direction is kept up and a uniform temperature maintained throughout the boiler.

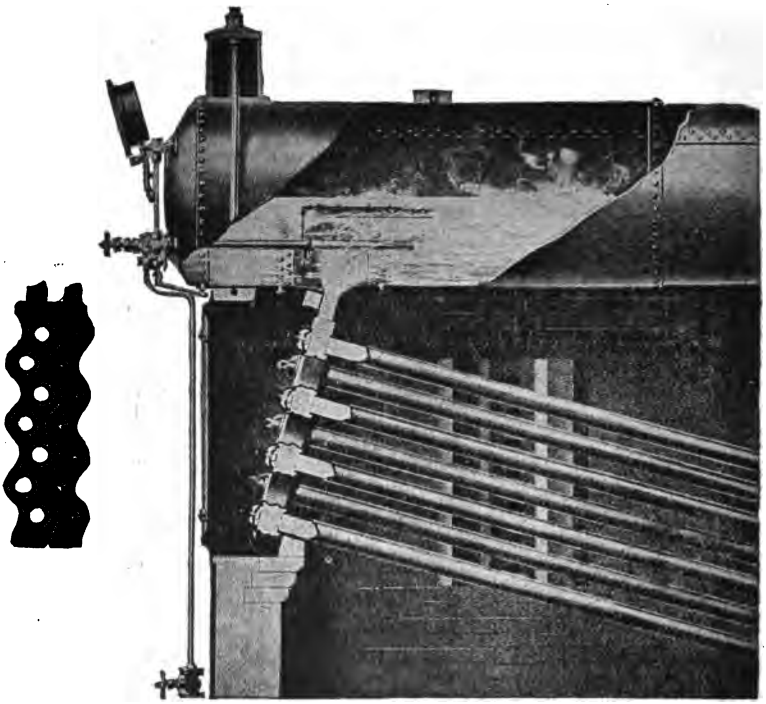


FIG. 147.—Part vertical section of Babcock & Wilcox boiler.

The third part of the boiler is the mud collector which is attached to the lowest point of the inclined water tubes, and into which any matter held in suspension in the water is to a large extent precipitated, by reason of its greater specific gravity, during the passage of the water through the vertical tubes and rear headers.

Erection.—The entire boiler, with the exception of the furnace, is suspended on mild steel girders and columns, thus enabling it to expand and contract without undue stress; this arrangement allows access to the brickwork without disturbing the boiler.

REPORT ON NORMAL LOAD TRIAL OF A BABCOCK & WILCOX BOILER WITH SUPERHEATER AND CHAIN GRATE STOKER AT THE LONDON AND SOUTH-WESTERN RAILWAY, WIMBLEDON, 1916.

General Description of Plant.

Boiler. — Babcock & Wilcox land type (steel cased), heating surface	5674 sq. feet.
Superheater. — Babcock & Wilcox (integral with boiler), heating surface	1540 ,,
Stokers.—Chain grates, dimensions double . . .	4′ 5″ × 14′.
Total grate surface	123 sq. feet.
Economiser.—Green's vertical tubes (steel cased), heating surface	2000 ,,

Particulars of Observations.

Date of trial . . . 1916 Duration of trial . . 10 hours.

Fuel.

Short description	Midland double-screened nut coal.
Name	Digby.
Fired per hour	2929 lbs.
Average thickness of fires . .	4¾ inches.

Analysis by weight of fuel as fired :—

Carbon	62·16 per cent.
Hydrogen	4·22 ,,
Sulphur	·67 ,,
Ash	12·56 ,,
Nitrogen, oxygen, and other constituents	10·07 ,,
Moisture	10·32 ,,
	100·00 per cent.

Calorific value of fuel as fired (lower value) . . 10,476 B.T.U. per lb.

Ash and Clinker.

Total per hour	313 lbs.
Percentage of fuel fired	10·7 per cent.

Flue Gases (Leaving Economiser).

Analysis of dry flue gases :—

	By Volume.	By Weight.
Carbon dioxide . . .	11·6 per cent.	17·0 per cent.
,, monoxide . .	Nil.	Nil.
Oxygen	7·5 per cent.	8·0 per cent.
Nitrogen (by difference) .	80·9 ,,	75·0 ,,
	100·0 per cent.	100·0 per cent.

Average temperature	320° Fah.
Mean specific heat of products of combustion .	·253

Air and Draught.

Temperature of stokehold	56° Fah.
Draught at gas exit from economiser	·51 inches of water.
,, ,, ,, boiler	·48 ,, ,,
,, over fire	·24 ,, ,,

Steam.

Gauge pressure	204 lbs. per sq. inch.
Temperature of saturation	389° Fah.
,, ,, superheated steam	588° ,,

Feed Water.

From pump per hour	22,084 lbs.
Temperature of feed to economiser	115° Fah.
,, ,, ,, boiler	180° ,,

Deductions.

Heat transmitted per sq. foot of heating surface per hour:—	
Boiler	4029 B.T.U.
Superheater	1627 ,,
Economiser	718 ,,
Weight of fuel fired per sq. foot of grate surface per hour	23·8 lbs.
Water evaporated per lb. of fuel as fired	7·54 ,,
Equivalent evaporation from and at 212° Fah. per lb. of fuel as fired	9·56 ,,
Air used per lb. of fuel as fired	13·01 ,,
,, theoretically required per lb. of fuel as fired	8·59 ,,
Ratio of air used to air theoretically needed	1·51 ,,
Weight (theoretically) of products of combustion per lb. of fuel as fired	9·46 ,,
Weight (actual) of gases per lb. of fuel as fired	13·88 ,,
Heat carried away in gases per lb. of fuel as fired	916 B.T.U.

Heat Account.

	B.T.U.	Per Cent.
Heat transferred to water in boiler	7928	75·68
,, ,, ,, steam in superheater	855	8·16
,, ,, ,, water in economiser	490	4·68
Thermal Efficiency of boiler, superheater, and economiser combined	9273	88·52
Heat carried away by products of combustion	632	6·03
,, ,, ,, excess air	284	2·71
Balance of heat account, errors of observation and unmeasured losses such as those due to radiation, escape of unburnt hydrocarbons, superheating moisture in air, loss in hot ashes, etc.	287	2·74
Total heat value of 1 lb. of fuel as fired	10,476	100·00

The Bigelow-Hornby Boiler.

The general construction of this boiler will be seen in Fig. 148, which shows a cross-sectional view through the brickwork of a

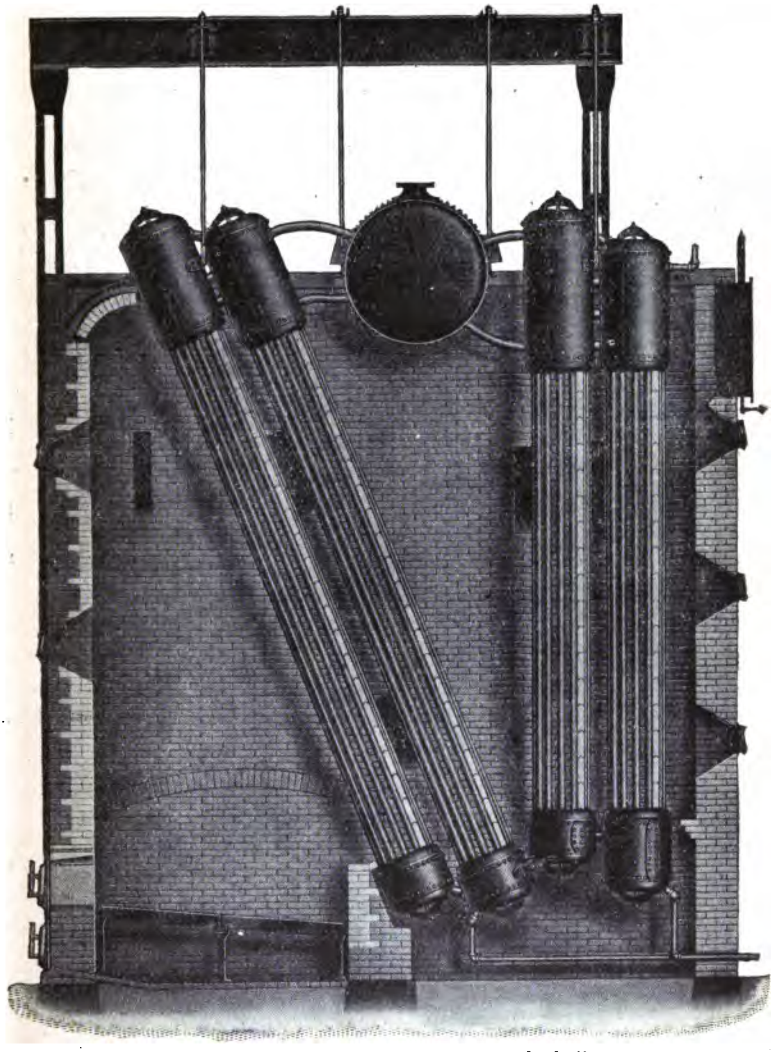


FIG. 148.—Bigelow standard water-tube boiler.

standard hand-fired boiler. The boiler is suspended entirely from overhead beams through the medium of long hangers. The main steam drum is the only rigid member used in the construction, and

since it is some distance from the furnace, the length which it can be made is practically without limit. The sections of the boiler, which are made up of four units each, are independent of the main steam drum and each other, except through the medium of long nipples connecting them with the top inside unit drums, and therefore a boiler

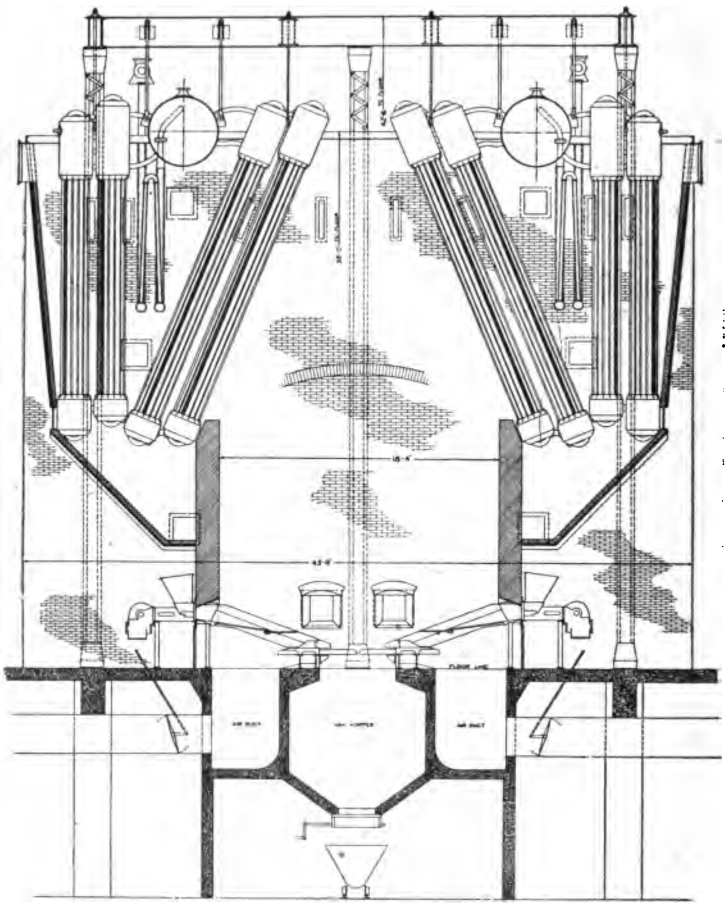


FIG. 148A.—Bigelow sectional boiler.

of ten or twelve sections width, or 1250 or 1500 horse-power, is no more affected by expansion strains than one composed of two or three sections.

Feed and Circulation.—The general circulation of water in this boiler is down the rear sections and up the front, and in addition to this there is a rapid circulation in the individual units. Owing to

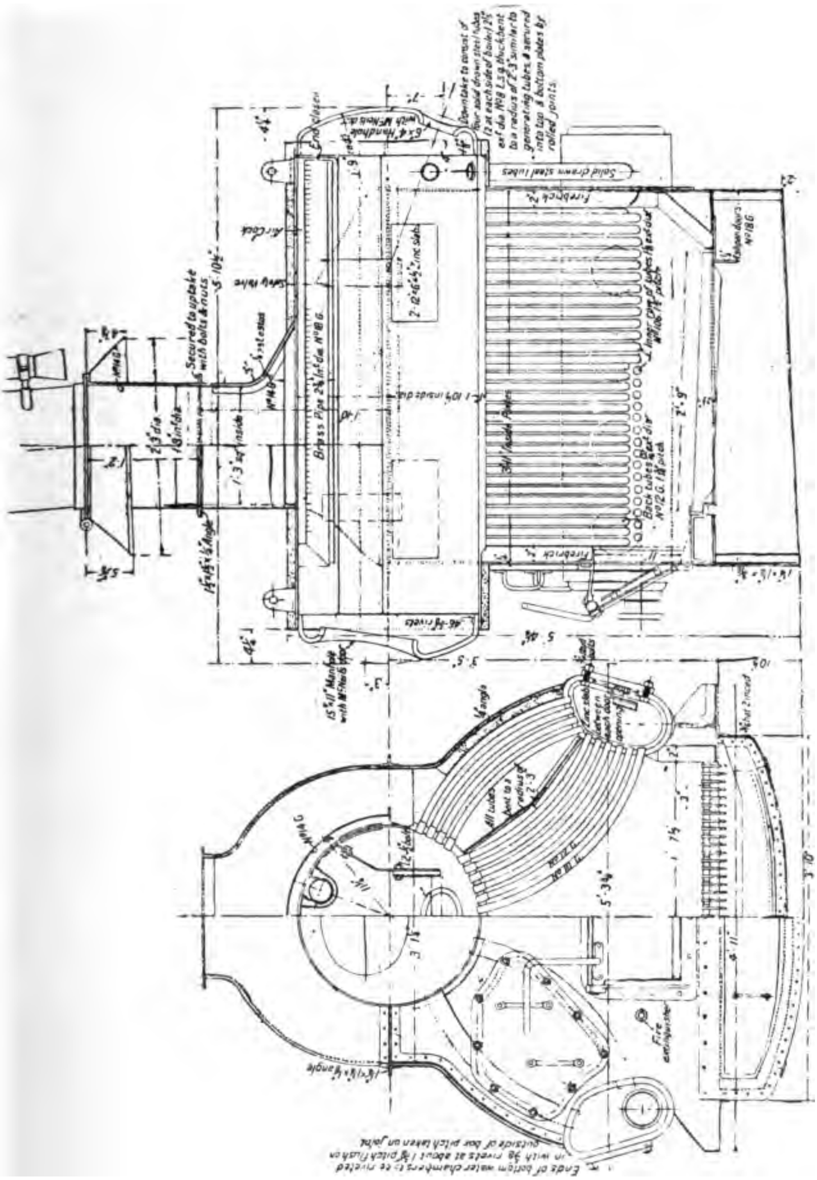


FIG. 149.—Mumford's water-tube boiler.

the fact that the water circulating nipples do not have to carry any of the steam generated, and that they are of considerably larger cross-sectional area than is usually used for similar capacities in water-tube boilers, the circulation in the Hornby boiler is very free and rapid. The feed enters the drums of the top rear units and mingles with the downward circulating currents in the rear tubes, and then passes up the tubes in the front units. It will be noted that the rear vertical units (comprising almost half the heating surface), which are in contact with the cooler gases of combustion, must be traversed by the feed water before it can come in contact with the direct heating surface of the furnace. This feature of counter-current flow, or that of the coldest water meeting the coldest gases, is considered a very important feature in all apparatus designed to produce maximum economy in the transmission of heat.

Accessibility.—The tubes can be removed through the front or sides, or through the top, according to the method rendered easiest by surrounding conditions; they are perfectly straight and only two lengths are used. The twenty-one tubes in each unit are reached internally by the removal of a single standard size manhole.

Fig. 148A shows an inner view of a double-ended boiler, which can be built in large units; it is possible by making up the boiler in 12 sections, that is by setting two 1500 horse-power boilers face to face, to obtain 3000 horse-power. The illustration shows the boiler equipped with a superheater and underfeed type of stoker.

The Mumford Water-tube Boiler.

The Mumford water-tube boiler is shown in part section in Fig. 149. It is of the small tube type, the tubes being slightly curved, and entirely submerged. The upper and lower ends of the tubes are expanded into steel headers, suitable doors being provided in the water chamber to enable the tubes to be thoroughly examined, and if necessary removed and replaced. The removal of any tube can be accomplished without disturbing any of the tubes surrounding it.

The standard size of this type of boiler is: Space occupied, 9 feet × 7 feet × 6 feet high; grate area, 22 sq. feet; heating surface, 850 sq. feet, giving an approximate indicated horse-power of 400.

CHAPTER IX.

BOILER MOUNTINGS.

Boiler Stop Valves.—The boiler stop valve is attached to the upper part of the boiler, and controls the passage of steam as it passes from the boiler to the main or sectional steam pipe. To accommodate the valve, a special casting of iron or steel is usually riveted directly to the boiler shell.

The different types of valves are innumerable, the details of construction depending to a great extent on the size of the valve, and the boiler pressure it has to control. With every description of valve the main object is to obtain a perfectly tight valve, and the great difficulty to be contended with is leakage. A very slight leakage soon leads to a bad leak, and for all pressures it is cheaper to fit the most efficient type of valve, constructed of sound and best quality metal, almost irrespective of the initial cost.

Valve leakage is frequently due to the unequal expansion of the metals used in its construction, to softening of the valve and valve seat, or to faulty design. With the valve body made of cast iron and the valve seating of gun metal, leakage and loosening of the seating can be attributed to unequal expansion of the different metals; the coefficient of expansion for cast iron is ·00000616 and for brass ·00001047, and it will be seen that under the influence of high temperatures the brass valve seating would expand to a greater amount than the valve body, which in time would possibly lead to a loose seating. With steam being generated at 250 lbs. per sq. inch a temperature of 406° Fah. would be obtained, and at this or any higher temperature the hardness of gun metal is considerably lowered, and when in that condition it becomes very liable to grooving; first, very slightly by particles of grit being pressed into the mitre of the seating, and afterwards by the grooving action of the steam passing at a high velocity between the valve and the valve seating. A frequent source of trouble with stop valves is the unequal expansion of the valve body, due to the want of symmetry and the difference in the thickness of the casting.

The continual heating and cooling to which stop valves are

subjected will distort to some extent the best designed and most carefully constructed valves, but if correctly designed and properly cast, any slight distortion will be overcome in tightening down the valve by means of the hand wheel.

Valve Construction.—All valves, whether for high or low pressures, should have an external thread on the valve spindle, and be fitted with a wrought-iron or steel cross-bar, into which the valve spindle is screwed. By this arrangement the thread is always exposed and ready for examination. In cases where the valve spindle is not screwed into the valve and secured, the collar at the end of the

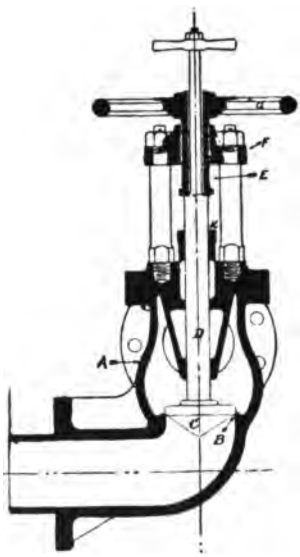


FIG. 150.—Section of Admiralty type self-closing stop valve.

spindle should be solid with the spindle, or screwed on and securely fastened by some safe method. Valves *not* provided with guiding wings are in all cases to be preferred, as they tend to prevent the irregular wear on the valve seats which is found to occur with wing valves. A very useful provision in a stop valve for correctly seating the valve and preventing grooving, is that in which the valve can be rotated by means of a double-handed lever independently of the hand wheel.

During a period of four years, sixteen valve casings within the writer's knowledge, working at from 70 lbs. to 200 lbs. pressure, were fractured by water hammer, and in every case the metal used was cast iron. It has been strongly recommended by the Government

Inspector of Factories that for pressures exceeding 120 lbs. per sq. inch, and for superheated steam, cast steel should be used for valve casings.

Self-closing Valves.—Fig. 150 illustrates a form of self-closing valve: A is the valve casing, with a seating for the valve at B. The valve C is attached to the valve spindle D, which passes through the

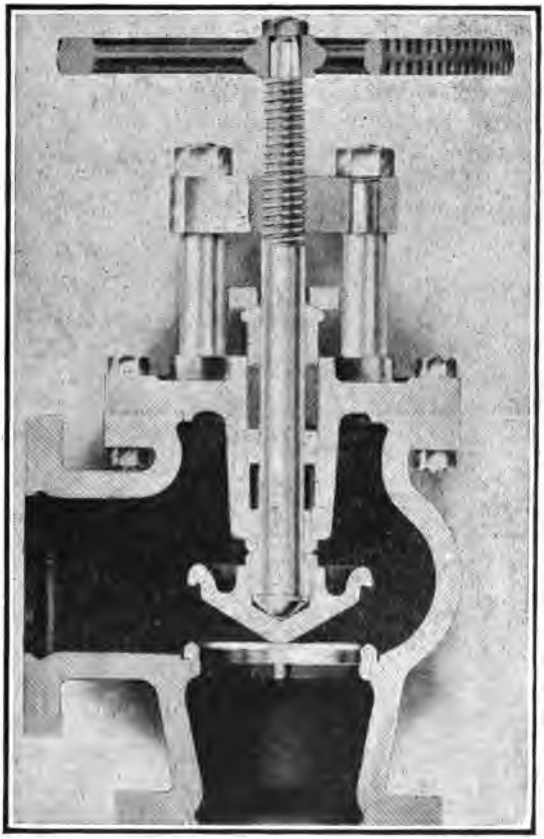


FIG. 151.—Main stop valve.

bush E, but is not attached to it. The bush E is screwed through to bridge F, and has a hand wheel G attached. If this hand wheel is turned in the required direction, the bush E will be moved through the bridge, and this will allow the spindle D to follow. It will be seen that the valve can be closed by means of the hand wheel, but not opened; this operation must be done either by pulling on the end of the spindle D, or by the steam pressure. The automatic

action of this type of valve is as follows: suppose the valve to be open and passing steam, then if from any cause the boiler was damaged sufficiently to allow steam and water to escape, the steam in other boilers would also tend to pass the valve into the damaged boiler. The rush of steam would, however, force the valve on to its seating and prevent any further escape of steam into the boiler. Care must be taken when opening this type of valve to see that when bush E is screwed back, the valve spindle follows, otherwise the valve may be blown violently out by the steam pressure. It is also necessary to see that the stuffing-box is carefully packed, and the valve spindle free to move up and down.

The form and construction of a good type of stop valve is shown in Fig. 151. The valve is the patent of Messrs. Alley & Maclellan of

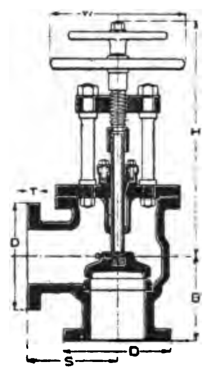


FIG. 152.—Section of Hopkinson's "Triad" junction valve.

Glasgow. The special features of this valve, which is suitable for pressures up to 200 lbs. per sq. inch, are: the gland which is of special design and cannot be unevenly tightened; repacking may be effected when the valve is full open; special shape of valve and valve seat; the chamfering combined with the shape of the internal valve throws the steam clear of the faces, and the projection on the valve throttles the steam until the faces are clear; the internal valve receives pressure from the spindle below the level of its working force, and so does not chatter and bruise itself; every time the valve is opened the internal valve rotates and finds a new position, thus keeping the forces level.

Fig. 152 illustrates a stop valve fitted with an improved expansion spindle which obviates the strains set up where gun metal spindles are used. It lessens the danger of bending or breaking the spindle, distorting the threads, or jamming the valves by the unequal

endwise expansion of the spindle over that of the valve body. The various dimensions of this valve are:—

Bore of Valve			2"	2½"	3"	3½"	4"	4½"	5"	6"	7"	8"	9"
Diameter of Flanges ..	British Standard. Table 2.	D	6½"	7½"	8"	8½"	9"	10"	11"	12"	13¼"	14½"	16"
Number of Bolts	British Standard. Table 2.	..	4	8	8	8	8	8	8	12	12	12	12
Size of Bolts	British Standard. Table 2.	..	⅝"	⅝"	⅝"	⅝"	⅝"	¾"	¾"	¾"	¾"	¾"	⅞"
Diameter of Bolt Circle ..	British Standard. Table 2.	.	5"	5¾"	6½"	7"	7½"	8¼"	9¼"	10¼"	11½"	12¾"	14"
Thickness of Flanges		T	⅝"	⅞"	1"	1"	1"	1⅛"	1⅛"	1¼"	1⅜"	1½"	1⅝"
Centre of Valve to Side Branch ..		S	5¾"	6½"	7"	7½"	8"	8¾"	9½"	10"	11"	12"	13"
Centre of Valve to Bottom Branch		B	4½"	5"	6"	7"	7¾"	8¼"	8¾"	9½"	10½"	11½"	12"
Height from centre to top nut above wheel (when open) ..		H	14½	15"	16½"	17"	23"	24"	25"	28"	29½"	33"	36"
Diameter of Hand Wheel ..		W	8"	8"	9"	9"	11"	13"	13"	15"	17"	20"	22"

Hopkinson-Ferranti Stop Valve.—This type of valve has the operative working parts of the valve situated in the narrow throat of the converging-diverging nozzle, which is about one-half of the diameter of the steam pipe in which the valve is situated. Although by this method of construction the valve parts are only about half the diameter of the pipe, there is no loss of pressure or throttling, owing to the special shape of the base, and the valve will pass an amount of steam equal to the full capacity of the steam pipe. The effect of this construction is to convert a portion of the pressure energy of the steam, as it travels into the converging nozzle on the inlet side, into kinetic energy, the steam increasing in velocity and dropping in temperature and pressure. At the high velocity thus acquired it passes through the controlling part of the valve proper. It now enters a diverging nozzle at high velocity, and in its passage converts its kinetic energy into increased pressure and temperature, until it has returned to the same condition of pressure, temperature and velocity with which it entered the converging cone at the inlet side of the valve. The construction of this patent valve is shown at Fig. 153.

Pressure Gauges.—At least one steam pressure gauge must be fitted to every boiler to indicate the pressure of steam in the generator. The absolute pressure in the boiler would be the pressure shown on the pressure gauge, plus the atmospheric pressure as indicated by the barometer.

In marine practice, it is usual to fit two steam pressure gauges to each boiler, one graduated to full working pressure, and the other to twice working pressure. In land boilers, it is more common to fit only one gauge, and this should be graduated to twice the working

pressure, and so arranged that the pointer of the gauge will be nearly vertical when the boiler is under working conditions.

The simplest and most usual type of pressure gauge fitted to land

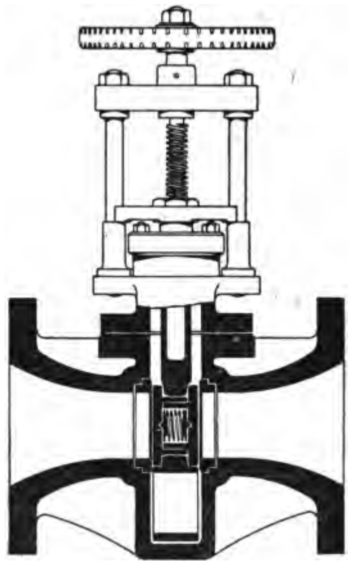


FIG. 153.—" Hopkinson-Ferranti " patent stop valve.

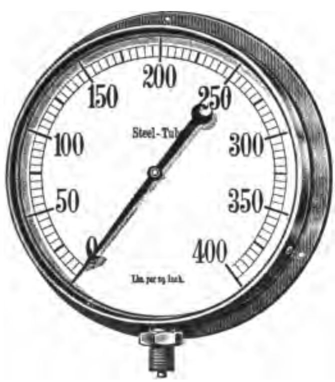


FIG. 154.—Steel-tube pressure gauge.

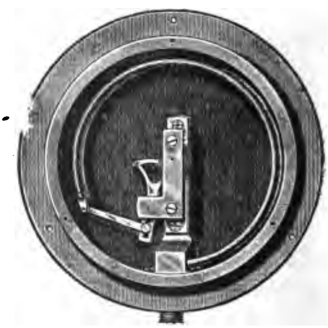
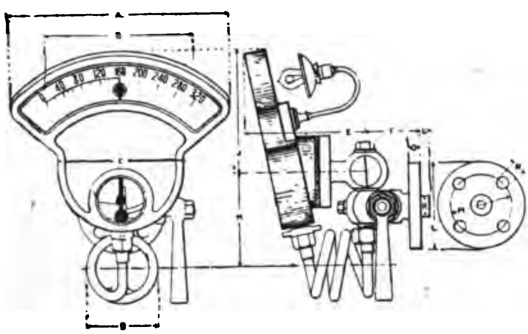


FIG. 155.—Bourdon gauge with back removed.

boilers is illustrated in Fig. 154, and the same gauge with its back removed is shown at Fig. 155. This gauge is the well-known Bourdon type, and consists of a curved tube of elliptical section, closed and connected at one end to a sector, provided with teeth, which gear with

a pinion wheel keyed to the spindle moving the pointer. The open end of the tube is placed in connection with the boiler pressure, and the pressure within the pipe tends to make the pipe section more nearly circular, and at the same time to straighten the pipe. When the internal pressure is relieved, the atmospheric pressure flattens the

Fig. 156.—Diaphragm pressure gauge.



A	B	C	D	E	F	G	H	J	K	L	M	N	O
19″	15″	11″	4″	9″	3″	$\frac{1}{16}$″	7″	$11\frac{1}{8}$″	$1\frac{1}{8}$″	$4\frac{3}{8}$″	$3\frac{7}{16}$″	$\frac{11}{16}$″	$\frac{3}{16}$″

Fig. 157.—Illuminated steam pressure gauge.

tube, and makes it more elliptical in section, and thus curves the tube again and brings the pointer back to zero.

For pressures below 100 lbs. per sq. inch, the tube is generally constructed of brass, while for pressures above 100 lbs. steel is mostly used.

A specially constructed gauge for use where a considerable amount of vibration is liable to take place is illustrated in Fig. 156. In this

type of gauge, instead of the pressure acting on the inside of an elliptical tube it acts directly upon a diaphragm as seen in the illustration. Another and more modern pressure gauge is shown at Fig. 157; the principle on which it is worked is the same as the Bourdon gauge, but it differs in shape, being provided, as can be seen, with a swivelled syphon pipe which effectively prevents steam from entering the gauge. An electric lamp illuminates part of the dial, and allows of the pressure being read with accuracy.

Self-recording Gauges.—When it is necessary to obtain a permanent record of steam pressure, the gauge shown in Fig. 158 can be used. Here a chart, moved by means of clockwork, records

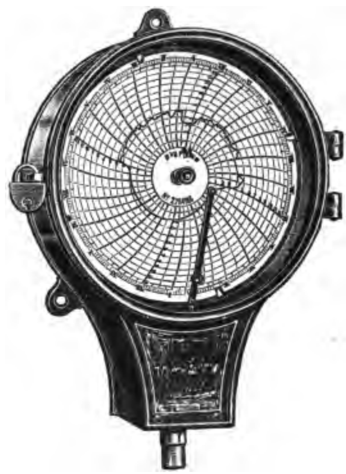


FIG. 158.—Self-recording gauge.

the pressure automatically, the pointer being actuated by the variations in the steam pressure. All pressure gauges should be fixed well above the boiler water level, in order to prevent as far as possible the admission of grit particles, which might find their way into the gauge tube. Overheating of the pressure gauge is likely to cause distortion of the working parts, and possible injury to the tube, and consequent false reading, therefore steam should be prevented from entering the gauge tube. To guard against overheating, a syphon pipe is generally fitted; on using the gauge, the legs of the syphon fill with water which is forced by the steam pressure into the gauge tube. Several different forms of syphon pipes are shown in Fig. 159, and at Fig. 160 two syphon pipes of the pillar type are shown, fitted with cocks for shutting off steam when necessary.

All pressure gauges when in use should be cold enough to be held by the hand.

Gauges in constant use are very liable to get out of order, and therefore they should be frequently tested and compared with a standard test gauge. It is also very important that gauges should be properly illuminated, and situated so that the boiler attendant can see the gauge pointer and pressure indicated without any difficulty.

Water Gauges.—Every boiler must be fitted with a water gauge, which should be of good make, and constructed from best quality gun metal or phosphor bronze. Steel or iron water gauge fittings are very unsuitable on account of their liability to rust and corrode.

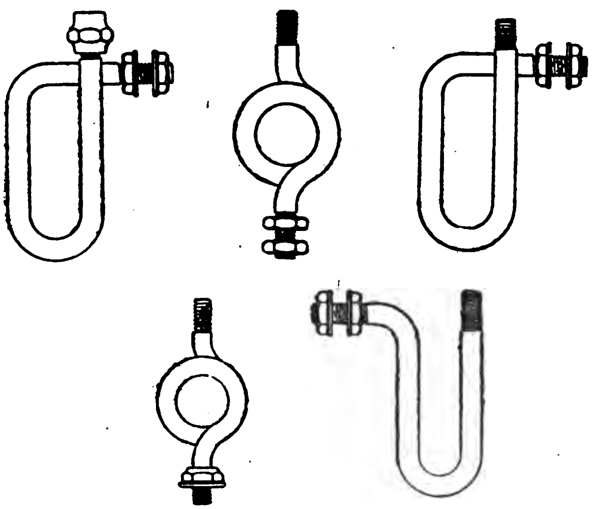


FIG. 159.—Pressure gauge syphons.

In the majority of land boilers, the water gauge fittings are bolted directly to the boiler plating, or on to specially constructed boiler mountings, riveted to the boiler front.

With marine boilers, the usual method is for the gauge fittings to be connected to the top and bottom part of the boiler by means of a pipe, and as this may possibly lead to a wrong water level being shown, the shorter and more direct the connections the better.

A very reliable type of water-gauge fitting is illustrated in Fig. 161; this shows the Hopkinson patent absolute water gauge; with this make of gauge, in the event of the glass bursting, the pressure in the lower arm forces the safety column ball A to its seat (as shown in dotted lines) and shuts off the escape of water. Simultaneously, the pressure in the supplemental tube J, together with the escaping

steam from the top arm, forces the automatic ball B to its seat (as shown by dotted lines), and so shuts off the escaping steam.

The escape of both water and steam having been effectually stopped, the gauge can be approached with absolute safety, and the cocks closed.

After the cocks C and D have been shut, the try cock E is opened, and this operation automatically drains the gauge; it will therefore be seen that the balls A and B will fall back by gravity into their normal working position. A new glass can then be inserted in the

FIG. 160.—Gauge syphons and cocks.

gauge, the steam and water cocks being opened, and the try cock closed; the gauge is then in its proper working position.

A water gauge with asbestos packing is illustrated at Fig. 162. The cock plugs do not rub on the metal of the casing, but upon asbestos packing, which is packed tightly into four longitudinal grooves in the body of the cock.

In order to protect the fireman from the effects of a burst gauge glass, some form of protector should be fitted. The simplest form consists of a glass shield, in the middle of which is embedded wire netting, the whole being held up to gauge mountings by means of springs as shown in the illustration.

Gauge Glass Packings.—The old method of packing circular

gauge glasses by means of rubber rings or asbestos packings has been superseded by the use of special cones. These do not choke the ends of the glasses, they allow for slight errors in alignment, put no torsional strain on the tube, yield to the expansion and contraction of the glass, and can be fitted in a few minutes. To fit the cones, the insides are wetted and they can then be slipped on the glass; the

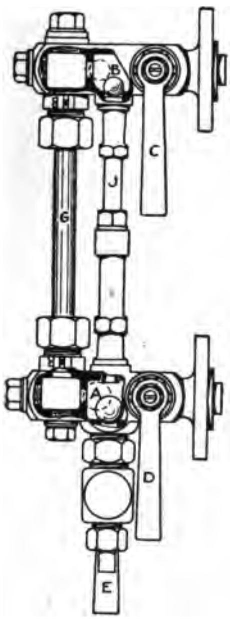


Fig. 161.—Section of water-gauge fittings.

Fig. 162.—Water-gauge glass protector.

gland ring E in Fig. 163 and the gland nut A are then gently screwed down, just sufficient to make a steam-tight joint on top of the stuffing-box.

Marine Gauge Glasses.—A form of gauge glass which is now largely fitted to marine boilers is illustrated at Fig. 164. This particular type can be fitted on boilers provided with the ordinary gauge fittings, the tube ends being inserted in the stuffing-boxes in the same manner as gauge glasses, care being taken that the packing is not

squeezed into the tube opening, and that the tubes are of correct length.

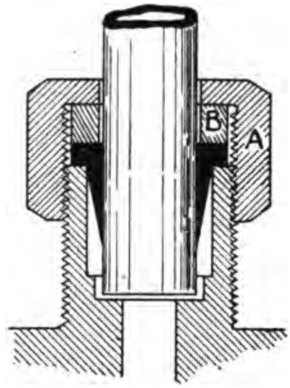
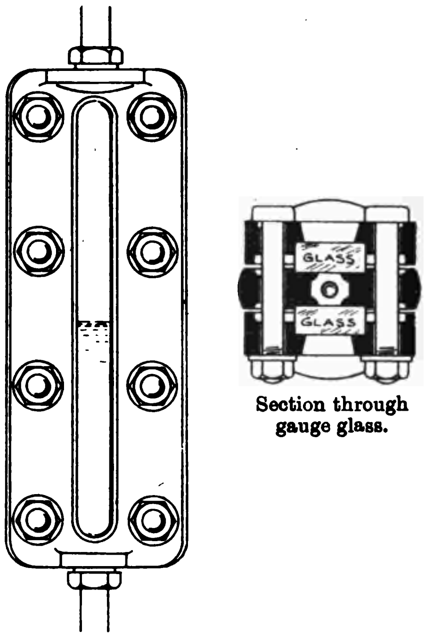


FIG. 163.—Diagram showing method of packing gauge glasses.



Section through gauge glass.

FIG. 164.—Transparent water level indicator.

The advantages of this gauge glass over the round glass tube are :—

I. The reliability with which the water level is shown.

II. Increased strength and proof against variations of temperature and pressure.

III. No stuffing-boxes to be packed should the glass require renewing.

This gauge consists of two frames and a distance piece, the frames having recesses into which the glasses are fitted, and the whole being held together by means of eight bolts. The joints between the glasses and the frames are made with some form of jointing material, or with red-lead putty.

To Test Water Gauges.—It is of great importance that water gauges should be tested regularly and correctly. Many furnaces have come down owing to faulty or incorrectly read water level. To test the gauge glass, first shut the bottom cock and open the drain;

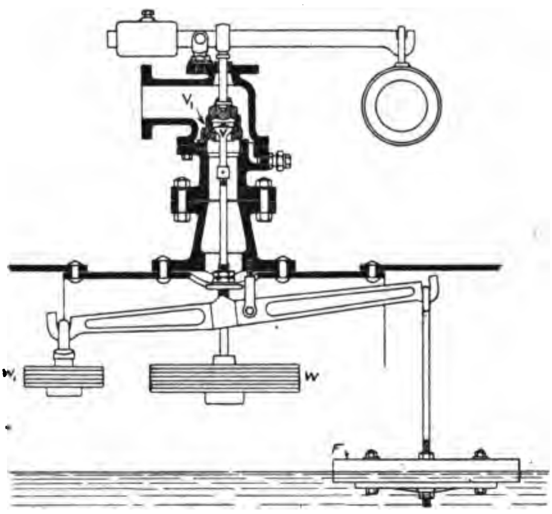


FIG. 165.—High pressure and low water safety valve.

steam should then blow through quite freely. Next shut the drain and top cock, and open the bottom cock and drain cock; water should then blow through. Shut drain and open top cock; open drain cock to blow through. Close drain, and the water should attain its correct level very quickly.

Test Cocks.—Test cocks are sometimes fitted to boilers to act as a check on the water gauge glass. When fitted they are preferably jointed directly on to the boiler end plate. They are generally three in number: one placed about four inches above the highest point of the combustion chamber; one at water level; and one about an equal distance in the steam space.

Safety Valves.—The safety device illustrated at Fig. 165 is a type of high steam and low water safety valve, extensively used in

Lancashire and Cornish boilers, and to a smaller extent in water-tube boilers. It was originally patented by Messrs. Hopkinson in 1852, and has proved of such value as to be almost universally adopted as a standard fitting for land boilers.

The construction is shown in the illustration. It consists of a main valve or cage V_1, loaded by means of an external lever and weight. In the interior of the cage a second valve V is seated, which is loaded

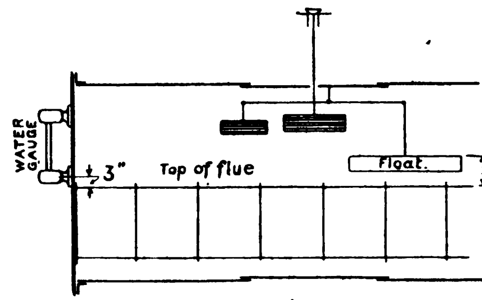


FIG. 166.—Diagram showing position of float for low water valve.

direct with the weight W. The latter valve is arranged to lift in the event of the boiler being low in water, this being operated by means of a lever to which is attached the float F and the weight W_1.

The lowering of the float causes the lever to lift against an adjustable washer secured to the spindle of the central valve, and thus give the alarm in the event of the boiler running short of water.

When an excess of steam pressure occurs, then the combined valves lift, and allow of the escape of steam.

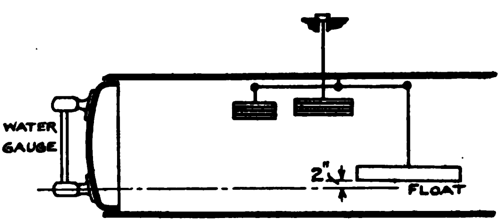


FIG. 167.—Diagram showing position of float for low water valve in water-tube boiler.

Position of Valve.—Fig. 166 shows the position of the safety valve as it should be placed in a Lancashire or Cornish boiler. The float, when there is water in the boiler, is immersed about $1\frac{1}{2}$ inches. As the boiler is tilted at the back end, the water gauge would show the water level about 1 inch above the glass nut when the valve was starting to blow for low water.

Fig. 167 shows the position of the valve as it should be fitted in a

water-tube boiler. The bottom of the float is placed 1 inch above the centre line of the bottom arm of the water gauge; this position allows the valve to blow for low water when the water level would show about 1 inch above the glass nut of the water gauge.

In a boiler where the valve is correctly set, the float should fall sufficiently heavily to open the valve when there is no water in the boiler.

Dead Weight Valve.—A modern type of dead weight valve is illustrated at Fig. 168. Here the valve V rests on a seating which is fitted in a flanged pipe G as shown; this pipe is jointed directly on

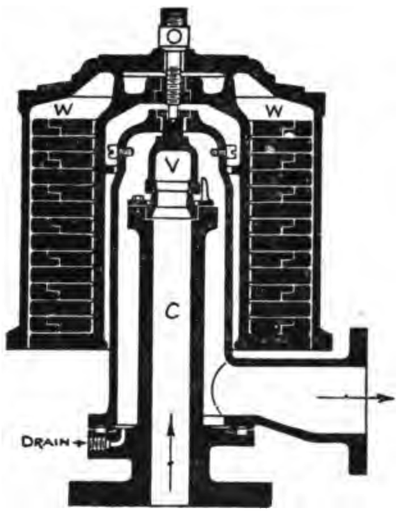


FIG. 168.—Dead weight safety valve.

to the boiler mounting. The valve and seating is enclosed so that the discharge of steam can be conveyed to any position desired by bolting the necessary piping to the flange provided for that purpose. The valve is held on to its seating by a number of weights, the preponderance of weights being below the valve seating. The valve is pendulously weighted, the whole of the weight being applied to the valve by means of a conical pointed pin.

The weights are enclosed in a case or cover which forms part of the weight required to load the valve, so that they cannot be tampered with and the valve is therefore safely loaded. The lift of the valve is controlled by means of two set screws, excessive lift being prevented by an annular ring filled to the inside of the cover.

Weight on Valve.

If p = steam pressure,
d = diameter of valve,
w = weight of cage weights and valve,

$$w = p \times \frac{\pi d^2}{4} = \text{lbs.}$$

Example.—If a boiler is provided with a 4-inch valve opening, what is the total weight on the valve to allow it to lift at 100 lbs. per sq. inch pressure?

$$p = 100 \text{ lbs. per sq. inch.}$$
$$d = 4.$$
$$\therefore w = \frac{100 \times 3{\cdot}1416 \times 16}{4} = 1256 \text{ lbs.}$$

Total weight of cage, weights, and valve, 1256 lbs.

Lever Safety Valve.—In Fig. 169 a simple and common type of lever safety valve is shown; here the weight W is balanced on a knife

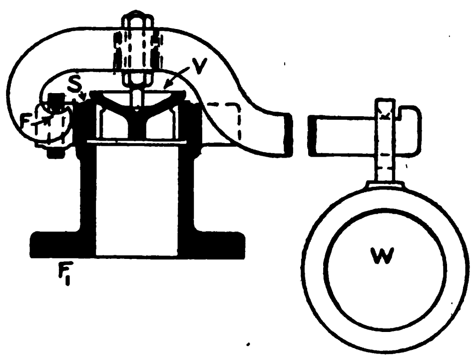


FIG. 169.—Lever safety valve.

edge at the end of the cranked lever. The lever is cranked in order to bring the knife edge of the weight as near as possible on a level with the conical-pointed pin which gives the pressure to the valve V. Both the valve V and the valve seating S are usually made of phosphor bronze. The advantage of having knife edges is that they do not rust; with pin joints it is possible for the pin to rust in the pin-hole and thus prevent the lever lifting.

A simpler type of plain lever safety valve fitted with pin joints is shown at Fig. 170.

The rule for finding the weight and length of lever can be taken as follows :—

In Fig. 171 let A = length in inches of the lever from the fulcrum to the point on the lever where the knife edge touches.

B = length in inches from the fulcrum to the centre of gravity.

C = length in inches from the fulcrum to the centre of the valve.

W = weight at end of the lever.

W_V = weight of valve in lbs.

W_L = weight of lever in lbs.

V = valve area in sq. inches.

P = steam pressure in lbs. per sq. inch.

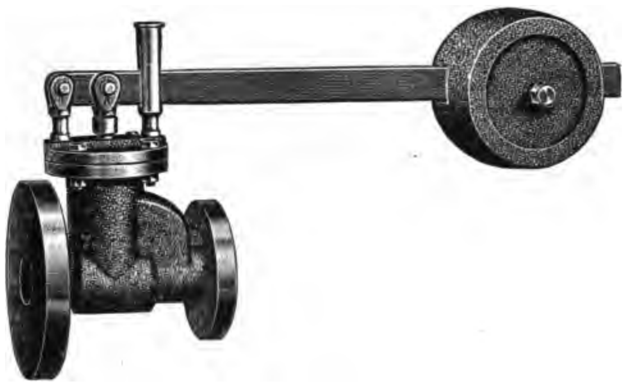


FIG. 170.—Simple type of lever safety valve.

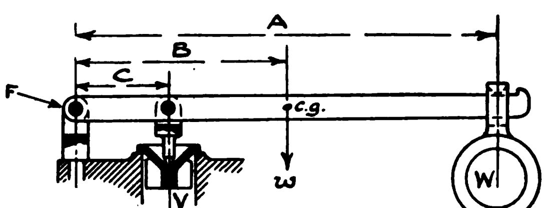


FIG. 171.—Diagram of lever and weight safety valve.

Note.—The measurements A, B, and C must be taken accurately, and the weight of the lever, valve, and ball weight ascertained by means of scales. The centre of gravity can be found by calculation or by balancing on a knife edge; if the lever is of uniform section its centre of gravity is at the middle of its length.

The weight of the lever multiplied by the distance of its centre

of gravity from the fulcrum is called the moment of the lever. The effective weight the lever exerts on the valve is found by multiplying the weight of the lever by the distance of the fulcrum from the centre of gravity, and dividing the product by the distance of the valve from the fulcrum.

Formula :—

$$W = \frac{(VP - W_V)C - W_L B}{A}.$$

$$A = \frac{(VP - W_V)C - W_L B}{W}.$$

Example.—If the diameter of a safety valve is 5 inches, the distance from the fulcrum to the centre of the valve 5 inches, the distance from the fulcrum to the centre of gravity 9 inches, the distance from the fulcrum to the weight 25 inches, the weight of the lever 10 lbs.,

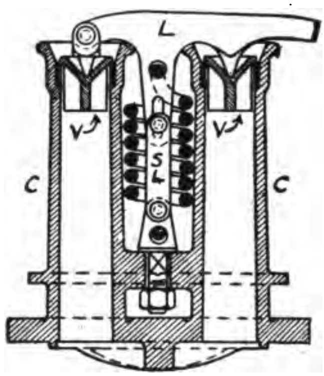


FIG. 172.—Diagram of locomotive type of steam safety valve.

and the weight of the valve 7 lbs., with steam pressure 60 lbs., per sq. inch, find weight at end of lever. Then referring to Fig. 171—

$$A = 25 \text{ inches} \qquad W_V = 7 \text{ lbs.}$$
$$B = 9 \quad ,, \qquad W_L = 10 \ ,,$$
$$C = 5 \quad ,, \qquad V = \frac{25\pi}{4} = 19{\cdot}635 \text{ sq. inches.}$$
$$P = 60 \text{ lbs.}$$

$$\therefore W = \frac{(19{\cdot}635 \times 60 - 7)5 - (10 \times 9)}{25} = 230{\cdot}6 \text{ lbs.}$$

To find length of lever from fulcrum to centre of weight :—

$$A = \frac{(19{\cdot}635 \times 60 - 7)5 - (10 \times 9)}{230{\cdot}6} = 25 \text{ inches.}$$

Ramsbottom Safety Valves.—Fig. 172 shows a Ramsbottom safety valve as fitted to British locomotives; this type of valve was

invented by Mr. Ramsbottom when he was locomotive superintendent of the London and North-Western Railway, and is used almost exclusively on locomotives.

The valve consists of a casting secured to the boiler mounting, and provided with two valves V, of precisely the same size, on the top of two pillars C; between the two columns is situated a coiled spring S, one end of which is hooked into an eye bolt fastened between the columns, the other end being hooked into the lever L. The lever is provided with pivots bearing on the valves, and is prolonged in order to provide a handle by means of which either valve can be tested. To prevent the valves being blown too far off their seats, two links L are provided, one end being secured to the eye bolt by means of a pin, the other end being also fitted with a pin which can move in a slotted hole in the hand lever, thus allowing the valves to lift if required.

As will be seen from the illustration, one spring holds down both valves, and if the diameter of the valves is D and the pressure p then the valves must be held down by a force equal to

$$2\,\frac{\pi D^2}{4}p\,;$$

or if the diameters of the valves are 3 inches and the pressure 150 lbs. per sq. inch, then the force must equal

$$\frac{2 \times \pi \times 3^2 \times 150}{4} = 2120 \text{ lbs.}$$

Fig. 173 illustrates a form of Ramsbottom safety valve used on the Government of India railway locomotives; it is shown partly in section.

Spring-loaded Safety Valves.

Spring-loaded safety valves may be fitted on boilers in passenger steamers instead of dead-weight valves, provided the following conditions are complied with :—

1. That at least two separate valves are fitted to each boiler.

2. That the valves are of correct area.

3. That the springs and valves are so cased in, and locked up, that they cannot be tampered with.

4. That provision is made to prevent the valves flying off in case of the springs breaking.

5. That screw-lifting gear is provided to ease all valves if necessary.

6. That the size of the steel of which the springs are made is in accordance with that found by the following formula :—

$$\sqrt[3]{\frac{s \times D}{c}} = d$$

where s = load on spring, in lbs.;
D = diameter of spring (from centre to centre of wire) in inches;
c = 8,000 for round steel; and
c = 11,000 for square steel.

7. That the springs are protected from the steam and impurities issuing from the valve.

FIG. 173.—Ramsbottom safety valve.

8. That, when valves are loaded by direct springs, the compressing screws abut against metal stops or washers, when the loads are on the valves.

9. That the springs have a sufficient number of coils to allow a compression under the working load of at least one quarter the diameter of the valve.

The number of coils required for a given compression, or the compression due to the load, is given, approximately, by the following formula:—

$$N = \frac{K \times C \times d^4}{s \times D^3}, \text{ or}$$

$$K = \frac{s \times D^3 \times N}{C \times d^4}$$

where N = number of free coils in the spring;
K = compression, in inches;
d = diameter of steel, or side of square, in sixteenths of an inch;
C = 22 for round, or 30 for square steel.
D and s are as above.

Fig. 174 shows a marine type of safety valve by Messrs. Cockburn, Glasgow. The various sizes are given in the following table:—

Dia. of Valve .	1½″	1¾″	2″	2¼″	2½″	2¾″	3″	3¼″	3½″	3¾″	4″	4¼″	4½″	4¾″	5″
Dia. of Inlet and Outlet . .	2⅜	2½	3	3¼	3⅝	3⅞	4¼	4⅝	5	5⅜	5¾	6	6⅜	6¾	7¼
A.	4⅞	4⅞	5⅛	6⅛	6⅛	7¾	7¾	8¼	8¼	8¾	8¾	9½	9½	9½	10
B.	7	7½	8¾	9	9½	10	10½	11	11½	12	13	13½	14	14½	15
C.	8	8	9½	10	10½	11	11¼	12¼	13	13½	14	14¼	14¾	15½	16
D.	7¼	7¼	8½	9¾	11⅛	12½	13¾	14⅞	16	17¼	18½	19¼	20¾	21¾	23¾
E.	5½	5½	7⅜	8	8½	9½	9½	9¾	9¾	11½	11½	12	12	12	12½
F.	1	1	1¼	1⅜	1⅜	$1\frac{9}{16}$	$1\frac{9}{16}$	1¾	1¾	1⅞	1⅞	2	2	2	2¼
G.	5½	5½	6⅜	6¾	7⅛	7½	7⅞	8¼	8⅜	9	9⅜	9¾	10½	10½	11
H.	5¼	5¼	5⅞	6¼	6⅝	6⅞	7¼	7⅝	8	8⅜	8¾	9	9⅜	9¾	10¼
J.	6	6	6¾	7¼	7¾	8¼	8½	9	9½	10	10¼	10¾	11¼	11½	12¼

Size of Safety Valves.—All boilers should be provided with two safety valves, which should be large enough to prevent any great increase of pressure. The Board of Trade rule for safety valve areas has determined that at 37·5 lbs. gross pressure of steam, 1 sq. inch of safety valve is required for every sq. foot of fire grate.

$$\text{Rule} \quad A_V = \frac{37{\cdot}5 \times G}{P}$$

where A_V = area of valve.
G = grate area.
P = gross pressure.

The minimum area of safety valves for different pressures as allowed by the Board of Trade for marine boilers is shown in the follow-

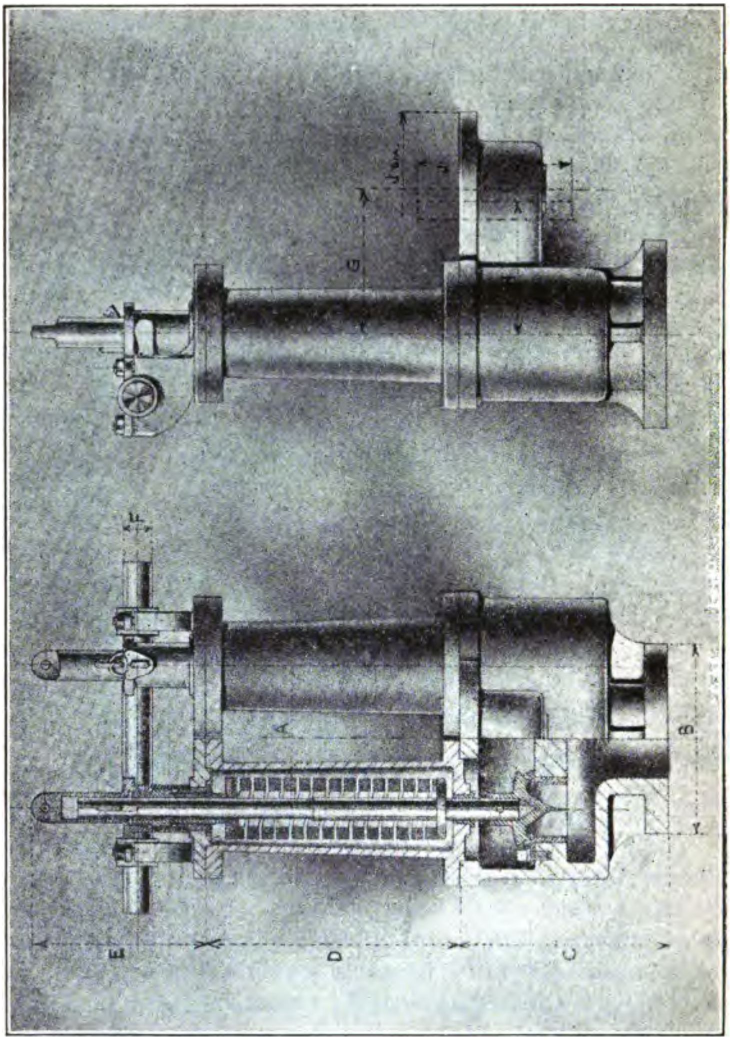


FIG. 174.—Marine type safety valve.

ing table. These figures are very suitable for use in calculating the size of safety valves for land boilers.

TABLE 25.—MINIMUM SAFETY VALVE AREAS.

Boiler Pressure.	Area of Valve in sq. in. per sq. ft. of Fire Grate.	Boiler Pressure.	Area of Valve in sq. in. per sq. ft. of Fire Grate.	Boiler Pressure.	Area of Valve in sq. in. per sq. ft. of Fire Grate.
50 lbs. sq. in.	·576	105 lbs. sq. in.	·312	160 lbs. sq. in.	·214
55 " "	·535	110 " "	·300	165 " "	·208
60 " "	·500	115 " "	·288	170 " "	·202
65 " "	·468	120 " "	·277	175 " "	·197
70 " "	·441	125 " "	·267	180 " "	·192
75 " "	·416	130 " "	·258	185 " "	·187
80 " "	·394	135 " "	·250	190 " "	·182
85 " "	·375	140 " "	·241	195 " "	·178
90 " "	·357	145 " "	·234	200 " "	·174
95 " "	·340	150 " "	·227	210 " "	·166
100 " "	·326	155 " "	·220	220 " "	·159

Fusible Plugs.—All boilers should be fitted with a good type of fusible plug. This provides a safeguard against collapsed furnaces and has frequently been the means of preventing disastrous boiler explosions.

A fusible plug fulfils its purpose if, when the water of a boiler is allowed to become low and the furnace plates get very hot, part of it melts and allows the steam to escape and put out the fire.

The plug generally consists of some form of gun-metal body, in the centre of which is run a fusible metal. The plug is screwed

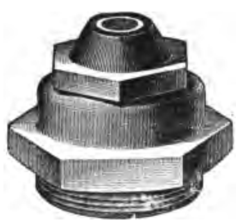


FIG. 175.—Fusible plug.

into the furnace tube directly over the hottest part of the fire, or, in the case of a locomotive, in the crown of the fire-box.

Fusible plugs should be periodically cleaned from scale or dirt, and the fusible metal should be renewed at least once every two years.

The simplest and commonest form of plug is shown in Fig. 175, and in Fig. 176 a new and improved type of plug manufactured by Messrs. Bailey of Manchester. The increase of boiler working pressure has made it necessary to reduce the bore of fusible plugs, and

this type of plug is specially made with a small aperture. The cap which protects the fusible metal is not held in any way, except by means of the fusible metal. The various parts of the plug are:—

A. Body of the plug.
B. Nut holding the fusible metal in position.
C. Fusible metal which is continuous and unbroken.
D. Lower cap which is free to fall through, and serves to protect the fusible metal from any injurious action from the fire-side.
E. Support for fusible metal; the upper edge is always above the lower edge of F, so that the cap has a clear way.
F. Upper copper cap protecting fusible metal from the action of water and scale.

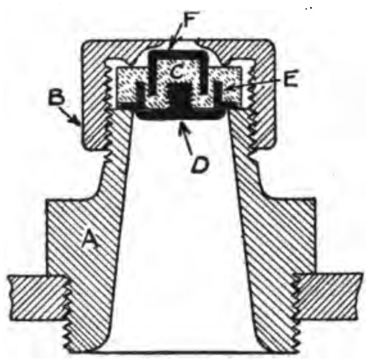


FIG. 176.—Section of "double copper cap" fusible plug.

Feed Check Valves.—To obtain the efficient working of any boiler, it is necessary that it should have a regular and continuous feed, and that the water should be kept and maintained at a constant height. To allow of these conditions, and also to prevent back pressure coming from the boiler, a good type of feed check valve must be fitted.

A reliable type of feed check is shown in Fig. 177. These are by Messrs. Alley & Maclellan, Glasgow, and represent the latest practice. Another type of valve very much adopted is shown in Figs. 178 and 179; this is Hopkinson's accessible back pressure feed check valve. Here the feed pipe is jointed on to the flange F, the feed passing through the elbow pipe E, past the check valve C which lifts or falls with the pressure, then past the stop valve V, the lift of which can be regulated by the hand wheel, and then into the boiler. Should the check valve start leaking, an inspection plug P is provided, and if it is found that the valve or seating is covered with scale, either of them can be removed for inspection or regrinding by closing the main valve V, and removing the elbow piece E which contains the check valve

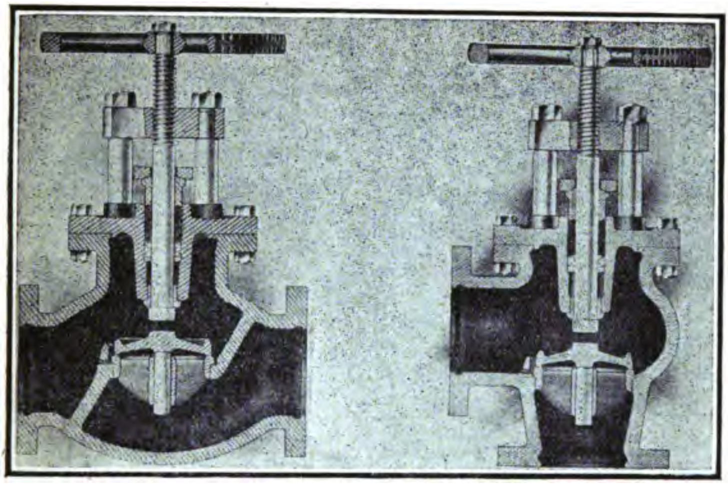


Fig. 177.—Feed check valve.

Fig. 178.—Feed check valve.

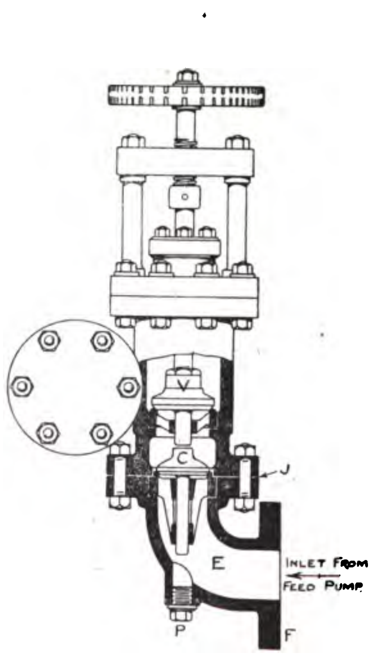


Fig. 179.—Section of accessible feed check valve.

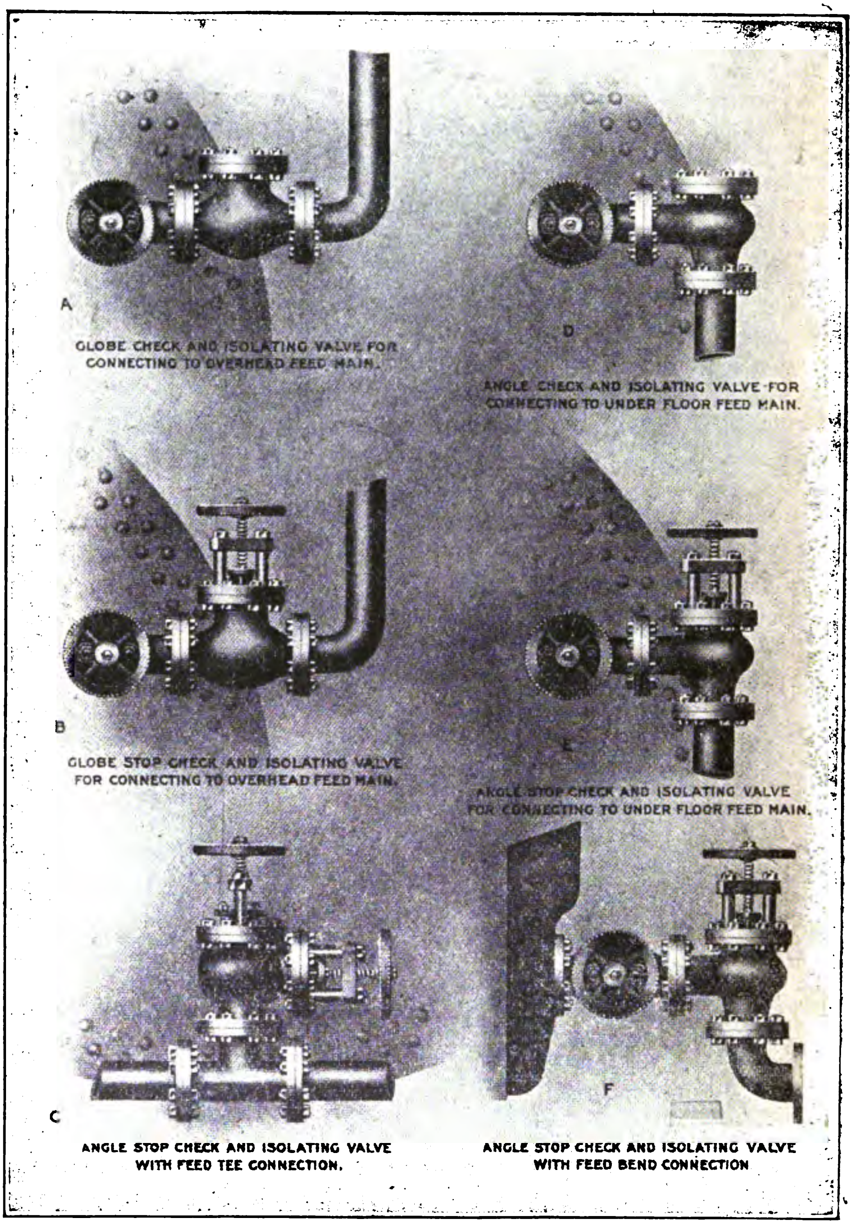


FIG. 180.—Boiler feed check arrangements.

and valve seat. After examination, cleaning, and regrinding, the valve is placed in position and the elbow piece rejointed, the operation being

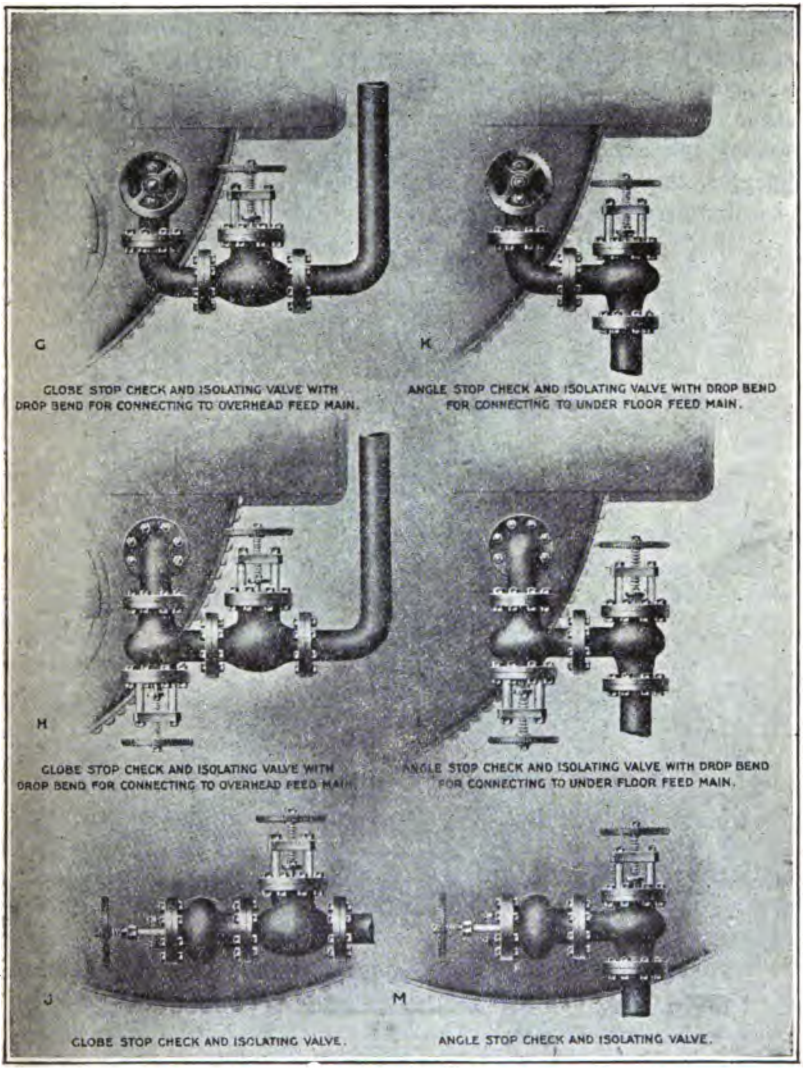


FIG. 181.—Boiler feed check arrangements.

performed without lowering the pressure and while the boiler is actually under steam.

Boiler Feed Connections.—Figs. 180 and 181 illustrate various methods of connecting boiler feed and isolating valves to boilers.

Blow-down Valves and Cocks.—Blow-down valves and cocks are fitted to boilers for the purpose of blowing out some of the water, or for entirely emptying it. A simple and ordinary type of blow-down valve is shown at Fig. 182. Many engineers prefer cocks instead of valves; instead of a single cock it is usual to fit a second and outer one. The cock close to the boiler should be a special one made from cast steel; the outer one can be of cast iron. When asbestos-packed cocks are used, and they are certainly the best for this purpose, care must be taken to see they are correctly fitted and adusted, otherwise a slight leakage of steam and water with the addition

FIG. 182.—Blow-down valve.

of a little grit will soon destroy the metal and packing. To keep the cock tight the plug when shut must be held firmly on its bearing of packing.

An asbestos-packed cock is quite free from the sand-blast action of escaping steam when fully open or shut, and to ensure this the inner of the two cocks is provided with a special cage arrangement which will only allow of the key to be put on or taken off in one particular position. When blowing down the boiler, the inner cock is first fully opened, the outer one being used to regulate the amount of discharge.

Fig. 183 shows a very good type of blow-down cock; in using this cock the handle is first put on the easing screw and turned about

half a turn. This slightly raises the plug and eases the pressure that kept it on its bearing. The handle is then taken from the head of the easing screw and put on the head of the plug. The cock can then be opened and the blowing off regulated and shut off again without much

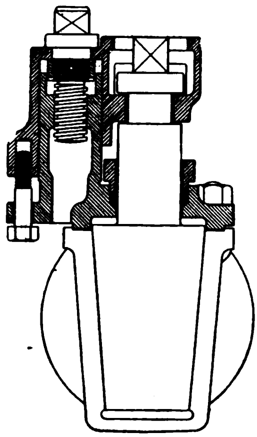


FIG. 183.—Blow-down cock.

friction. When the cock is shut off, the handle is again taken from the head of the plug and put on the head of the easing screw, which is screwed down reasonably hard, forcing the plug on to its proper bearing again and preventing leakage.

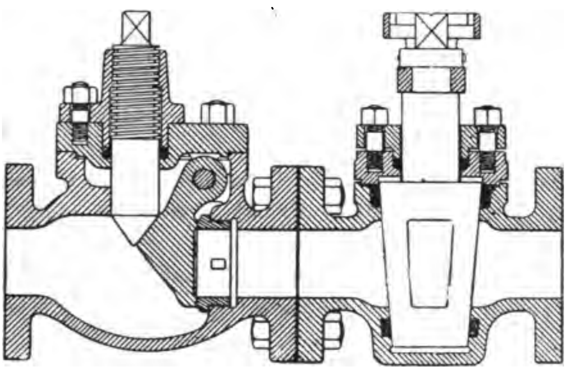


FIG. 184.—Section of adjustable isolating valve and blow-down cock.

The arrangement illustrated in Fig. 184 consists of a blow-down cock with the addition of an isolating and regulating valve. The construction of the valve is clearly shown in the drawing. The amount of discharge can be regulated by unscrewing the valve spindle.

Blow-off Connections.—When the blow-down pipe of a boiler runs into a common discharge connecting two or more boilers, a great element of danger is always present, and persons working in the empty boiler run a considerable risk, unless proper precautions are taken.

The blow-down cocks of empty boilers are frequently left open, and should any of the blow-down cocks of the working boilers be opened, then the escaping steam or boiling water will probably be forced into the empty boiler. When the blow-down pipe of a boiler is connected to a drain a further danger arises; on cooling after blowing down

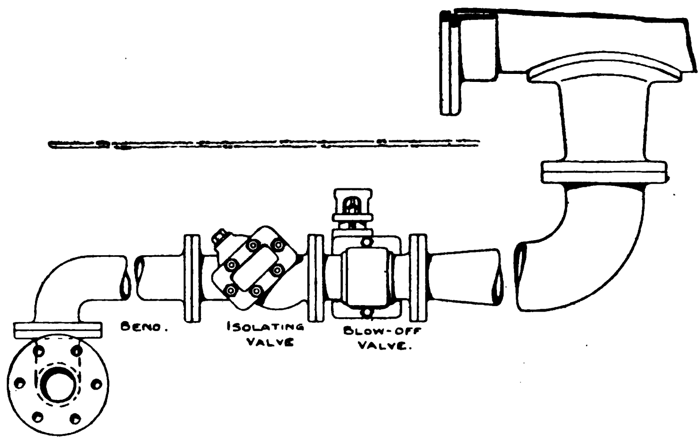


FIG. 185.—Method of connecting blow-down valve, isolating valve and connection to drain.

a vacuum is created and the atmospheric pressure in the drain may force poisonous gases into the boiler.

In all cases where two or more boilers connect to a common drain, some form of isolating valve should be fitted to each boiler, the arrangement shown in Fig. 185 being quite reliable.

Air Cocks.—Small asbestos-packed cocks are usually fitted to the higher part of the boiler, to allow the escape of air when lighting up.

Scum Cocks.—Scum cocks are not fitted to boilers to anything like the extent they were a few years ago; the use of clean water has done away with the need for scumming.

Position of Boiler Fittings.—Fig. 186 illustrates a dry back marine type boiler, and the various fittings are :—

A. Stop valve.
B. Safety valve.
C. Pressure gauge.
D. Blow-down valve.
E. Water gauge.
F. Feed valves.

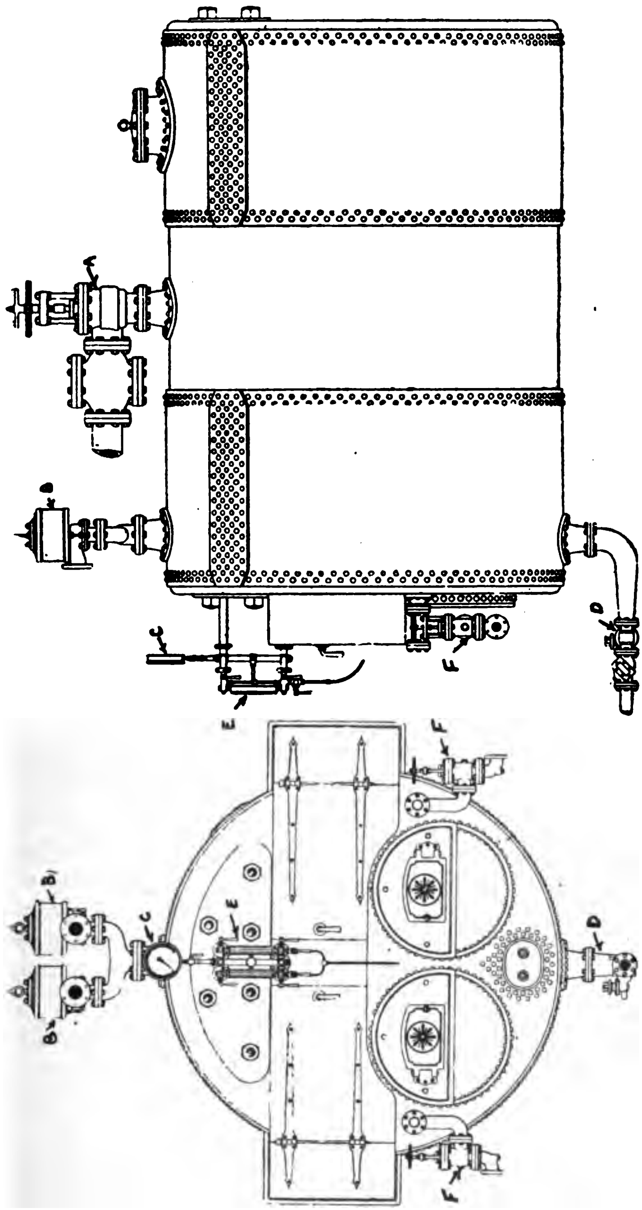


FIG. 186.—Diagram showing position of various fittings on marine boiler.

CHAPTER X.

BOILER FEED WATER.

THE economical raising of steam, the period of time between each boiler scaling, the freedom from leaky seams and collapsed furnace crowns, depend to a very large extent upon the suitability of the boiler feed water for steam-raising purposes.

When water contains corrosive or scale-forming substances, it is quite obvious that, should the water be introduced into a boiler without first removing these impurities, then corrosion may take place, and scale may be formed.

Pure water is a chemical compound consisting of one part of hydrogen and eight parts of oxygen by weight, the chemical formula being H_2O. A perfectly pure water is never found in nature, the reason for this being that water in all cases comes in contact with either solid, liquid, or gaseous materials, from which it may derive impurities.

The source of the supply of a natural water will often determine the character and composition of the water obtained.

Rain Water.—Rain in its descent from the clouds in most cases comes in contact with carbon dioxide or ammonia, and being an active absorbent for gases it quickly becomes more or less impregnated. In the neighbourhood of towns sulphurous and chlorine gases are frequently present, and thus the rain may absorb impurities.

Surface Water.—Surface water is generally found free from mineral matter, but may contain impurities derived from decayed vegetable matter. It will often be found that surface water contains considerable quantities of insoluble substances that have been carried along in suspension.

Spring Water.—Spring water will often be found to contain gaseous and mineral impurities which have been obtained by the water coming in contact with decayed animal, mineral, and vegetable matter.

River Water.—Being a mixture of spring, surface, and rain water, the water from a river will contain the impurities found in

each, and often, in addition, finely divided clay and mud will be held in suspension.

The following is a list of the impurities commonly found in water :—

Calcium Carbonate ($CaCO_3$).—This salt dissolves very freely in water containing carbonic acid, forming calcium bicarbonate. In its pure state calcium carbonate is very slightly soluble in water. The soft scale found in boilers is mainly formed by calcium carbonate. It can be removed by absorbing or expelling the carbonic acid.

Calcium Chloride ($CaCl_2$).—Calcium chloride is not a scale-forming salt, but it is very objectionable in boiler feed water owing to its ability to decompose sulphates and form calcium sulphate. It can be removed by means of sodium carbonate.

Calcium Sulphate $Ca(SO_4)$.—Calcium sulphate forms a very hard scale, and attaches itself very firmly to hot boiler plates. It is soluble in water, but precipitates on concentration at high temperatures. It can be precipitated by sodium carbonate.

Calcium Nitrate $(CaNO_3)_2$.—Nitrate of calcium does not form a scale, but in the presence of sulphates may form calcium sulphate scale. Can be precipitated by the use of sodium carbonate.

Magnesium Carbonate ($MgCO_3$).—Magnesium carbonate is very similar in effect to calcium carbonate. In its normal state it is only slightly soluble, while in the presence of carbonic acid it readily forms a bicarbonate. Its removal can be effected by the use of slaked lime.

Magnesium Sulphate ($MgSO_4$).—Magnesium sulphate is not in itself a scale-forming salt. It is soluble in water, and should the water contain calcium carbonate, the two, under the influence of heat, may react and form calcium sulphate and magnesium carbonate. It can be removed by the use of sodium carbonate.

Magnesium Chloride ($MgCl_2$).—Magnesium chloride is often the cause of boiler corrosion. It is very soluble, and high temperatures will decompose the magnesium chloride and form hydrochloric acid. Its removal can be effected by sodium carbonate.

Sodium Carbonate (Na_2CO_3).—Sodium carbonate does not form a scale. Priming and foaming is often attributed to the presence of this salt. It is treated with lime and calcium or aluminium sulphate.

Sodium Chloride (NaCl).—This salt does not form a scale, but in the presence of scale-forming salts or precipitated impurities is likely to cause foaming and priming. It can only be eliminated by distillation.

Sodium Sulphate (Na_2SO_4).—This salt is similar in action to sodium chloride. It cannot be eliminated except by distillation.

Alumina and Iron Salts.—Alumina in minute quantities is found in most waters, and iron exists in water as a bicarbonate.

Carbon Dioxide (CO_2).—Evolved by decayed organic matter and found in nearly all natural waters, holding calcium, iron, and magnesium in solution as bicarbonates. It can be removed by treatment with lime.

Silica (SiO_2).—Exists to a limited extent in all natural waters, and when present in quantity will unite with scale-forming salts and considerably harden the scale.

Analysis of Water.

The result of a water analysis is generally expressed in parts per 100,000. One gallon of water weighs 10 lbs. or 70,000 grains, therefore the results obtained divided by 10 give lbs. per 1000 gallons, and multiplied by 0·7 give grains per gallon.

The following is a typical analysis of a well water :—

	Grains per Gallon.
Sodium sulphate	18·96
Magnesium sulphate	12·41
Calcium carbonate	10·96
Sodium chloride	5·25
Calcium sulphate	2·39
Magnesium carbonate	2·67
Silica	0·32
Total solids	52·96

Hardness.

The most troublesome impurities found in natural waters are inorganic, and comprise salts of lime and magnesia, oxides of iron, and free carbonic and sulphuric acid.

The salts of lime and magnesia are the cause of what is known as hardness. They can be divided into two groups, one group being the easily decomposed bicarbonates and the other the more stable chlorides, nitrates, and sulphates.

Hardness is a comparative term usually expressed in degrees, one degree being equivalent to a solution of one part by weight of sulphate, carbonate, or other scale-forming salt in 100,000 parts of water. The older method of expressing hardness is by taking the number of grains per gallon, and as a gallon of water weighs 10 lbs. or 70,000 grains, one grain per gallon must equal 1·4° of hardness.

Temporary Hardness.—Temporary hardness is due to the

presence of carbonates of lime, magnesia, and iron dissolved by the carbonic acid in the water. These salts on evaporation are thrown out of solution, because boiling the water causes the decomposition of the bicarbonate of lime and magnesia, half the combined carbonic acid being driven off, converting the bicarbonates into normal carbonates.

Permanent Hardness.—This is due to the sulphates, chlorides, and nitrates not effected by boiling, which remain dissolved in the water, and which are not precipitated at a temperature below boiling-point.

Testing for Hardness.

Total Hardness.—The total hardness of a sample of water is ascertained by determining the amount of standard soap solution that is required to give a permanent lather to a fixed quantity of water. The usual method of obtaining this is to take 70 c.c. of the water to be tested in a stoppered bottle, and a suitable amount of soap solution in a burette.

The soap solution is added to the water 1 c.c. at a time and the bottle shaken; this is continued until a lather is obtained that will last five minutes. To calculate the hardness in the water, subtract 1 c.c. from the amount of soap solution used, and the remaining number of cubic centimetres used will give the total hardness in Clark degrees or grains per gallon.

Permanent Hardness.—To find the permanent hardness of a sample of water measure out 250 c.c. of the water, transfer to a conical flask and boil for three-quarters of an hour, at the same time keeping the volume up to 250 c.c. by adding distilled water from time to time. Cool quickly and transfer to a 250 c.c. flask, making up the volume accurately to 250 c.c. Titrate 70 c.c. of the water with standard soap solution and calculate as above.

Temporary Hardness.—To find temporary hardness subtract the permanent hardness from the total hardness.

Boiler Deposits.

As an example of the amount of solids which may deposit in a boiler either in the form of scale or sludge, let the total solids per gallon of feed water be 20 grains, and the evaporative power of the boiler 9000 lbs. per hour. Then the total solids deposited per day of 12 hours would be obtained as follows: $9000 \div 10 = 900$ gallons per hour, and $900 \times 20 = 18{,}000$ grains per hour, i.e. $18{,}000 \times 12 = 216{,}000$ grains per day. Taking 7000 grains to the lb. the weight of deposit per day would be $216000 \div 7000 = 30{\cdot}8$ lb.

Boiler Scale.

The possible amount of boiler scale forming in a boiler supplied with unpurified water can be calculated approximately from an analysis of the water.

Scale formed in a boiler supplied with feed water in which the hardness is mostly temporary will, as the following analysis shows, consist mainly of carbonate of lime.

Analysis of scale formed in a boiler fed with London water :—

Calcium carbonate	87·7
,, sulphate	6·3
Magnesium hydrate	3·5
Silica	1·6
Oxide of iron	0·14
Organic or volatile matter	1·3
	100·44

An analysis of boiler scale is not considered sufficient to give a true indication of the impurities which exists in the feed water from which it was formed, owing to the reactions which may take place under the influence of heat. The same applies to the testing and analysis of the feed water; here again the results obtained by analysis will not give a true indication of the amount or nature of the scale that will be formed.

The amount of scale deposited in a boiler depends upon—

The impurities in the water.

Rate of evaporation.

Position of heating surfaces.

The amount of scale-forming impurities in a feed water can be ascertained by analysis and eliminated by treatment outside the boiler.

The rate of evaporation must naturally have a large influence over the total scale deposited, the amount of the latter varying directly with the amount of water evaporated.

The position of the boiler heating surfaces determine to a great extent the position and thickness of the scale, the plates evaporating the greatest amount of water receiving the largest quantity of scale.

Scale-forming impurities present in boiler feed water are bad for a boiler in many ways. Scale is a bad conductor of heat, and consequently the fuel combustion, for a given evaporation, must be increased. The deposit of scale on boiler plates will in all cases raise the temperature of the plate above normal, and may lead to abnormal strains being set up in the plates. Scale may, and frequently does, conceal wasting and corrosion. The necessary cleaning and scaling

of boilers using unpurified feed water requires that the boiler shall be put out of action for several days, and the cost of scaling must be taken into account.

Oil Deposit.

Of all the impurities commonly found in boiler feed water, oil is probably the most dangerous and at the same time the most difficult to eliminate. Oil deposited on furnace tubes means a decrease in the evaporative efficiency of the boiler, the grease film preventing the steam bubbles from freely leaving the hot plates and thus retarding the transmission of heat from the plate to the water.

The presence of oil on the furnace plates frequently leads to local overheating, causing cracks and bulging in the plates, and sometimes collapsed crowns.

Water impregnated with salts of magnesia appears to emulsify with greasy feed water, and give a milk-like appearance to the water, forming a flower-like deposit which prevents the free ebullition of the steam bubbles.

Testing Water for Oil.—The test for oil is usually made as follows: About one pint of water is placed in a separating funnel provided with a glass stopcock and stopper, 20 c.c. of petrol-ether is added and the whole is vigorously shaken. The oil, if any is present, is dissolved by the petrol-ether, and on standing the solution will separate itself from the heavier water and will float on the surface. The water is then run off by the stopcock; the ether solution is emptied into a porcelain basin, and is placed in a warm place free from dust for the ether to evaporate. The residue will be the oil contained in the quantity of water used.

Corrosion.

The causes to which corrosion is generally attributed are:—

1. The introduction into the boiler of animal and vegetable oils.
2. The presence of air in the feed water.
3. Galvanic action.
4. Salt water.

1. Internal corrosion is frequently caused by free acids forming in the boiler. The decomposition of vegetable or animal oil, or the decomposition of acid salts and organic matter, in the presence of a high temperature, will in most cases set up corrosion more or less serious.

When a boiler that has been under steam for some considerable time shows a black or reddish deposit, it is an indication that corrosion is probably taking place.

Some feed waters are naturally acid, the acid probably being of an organic nature. In some cases acids have been known to percolate into water and thus cause serious corrosion both to feed pipes and the boiler.

2. It has been proved that the introduction of air into a working or standing boiler may cause corrosion. Air introduced with feed water, being heavier than steam, will attach itself in the form of bubbles to the hot plates; the oxygen acting on the iron or steel plates forms oxide of iron, with the result that with the constant rusting and washing away of the rust pitting will take place. When once pitting starts it progresses very rapidly, because the holes form cavities for the air to lodge in.

3. It was common at one time to attribute all corrosion taking place in boilers to galvanic or electrolytic action. This may be to some extent true, as under the influence of heat and in the presence of gases small currents of sufficient strength to produce corrosion may be set up.

It is often very difficult to account for corrosion for the reason that certain parts of a boiler are affected often where least expected. When it is found that plates close to gun-metal or brass fittings are attacked, then galvanic action is probably the cause, and suitable precautions should be taken.

4. The possible introduction into a boiler of salt water would more generally apply to marine boilers. The composition of sea water varies considerably, but the following analysis may be taken as giving approximate average quantities of its various constituents:—

	Grains per Gallon.
Carbonate of lime	9·20
Sulphate of lime	112·45
„ of magnesium	160·26
Chloride of magnesium	261·91
„ of sodium	1870·86
	2414·68

It has been found that sea water coming in contact with hot boiler plates will, under certain conditions, become acid, the reason being that chloride of magnesium is converted into hydrochloric acid and magnesia. The hydrochloric acid may dissolve iron from the plate surfaces and form chloride of iron; as soon as the chloride of iron is formed, it is decomposed by the magnesia already liberated, precipitating oxide of iron and re-forming chloride of magnesia. The acid

formed in the water is local, being developed whilst the water is in contact with the hot plates and is immediately afterwards destroyed by reuniting with the magnesia. Hence iron is never found in solution in boiler water, and the water, if no acid were introduced with the feed water, would never be found acid. The oxide of iron deposited is ferrous oxide, and is black in colour, and remains so, unless air is allowed to get in the boiler, when it becomes ferric oxide and changes in colour from black to red. See also page 269 for notes on corrosion.

Testing for Salt.

The most reliable method of testing distilled boiler feed water for salt is by means of silver nitrate ($AgNO_3$). Silver nitrate is a white crystalline substance, and dissolves in its own weight of water, but a solution of 3 per cent. by weight is sufficiently strong for testing purposes.

One drop of silver nitrate solution, placed in a test tube containing water in which salt (sodium chloride, $NaCl$) is present, will be sufficient to immediately cause a white cloudy precipitate, the reactions being :—

$$\underset{\text{Silver nitrate}}{AgNO_3} + \underset{\text{Sodium chloride}}{NaCl} = \underset{\text{Silver chloride}}{AgCl} + \underset{\text{Sodium nitrate}}{NaNO_3}$$

The silver chloride forms a white precipitate, and is practically insoluble in water, and the sodium nitrate remains in solution.

This test will determine the presence or absence of salt; it is qualitative only, and simply indicates, very approximately, how much salt is present.

The Purification of Feed Water.

The Elimination of Oil.—Oil separators placed between the feed pump and the boiler will remove a great portion of the grease contained in the feed water, but no filter, however efficient, will entirely remove the oil present. It is found that oil globules are likely to be in an emulsified state no larger than $\frac{1}{100,000}$ of an inch in diameter, and for that reason no filtering medium can be obtained that is fine enough to prevent the escape of these small globules.

The only satisfactory and efficient method of dealing with emulsified oil in feed water, especially when it is obtained from the hot well of land engines, is by means of suitable reagents; these reagents entangle the oil in a precipitate which can afterwards be filtered out.

The process generally adopted is to add small and fixed quantities of sulphate of alumina and carbonate of soda to the water, the result

of the interaction of the substances being a flocculent precipitate of aluminium hydroxide, which retains the oil and is removed by filtration, and a small quantity of sulphate of soda which, together with a small excess of carbonate of soda, remains in solution in the purified water.

Prevention of Corrosion.—Corrosion can be prevented to a great extent by effectively neutralising any acid in the feed water by the addition of an alkali such as soda ash.

Care should be taken that no air leaks occur in the feed pump suction, and all air possible should be eliminated from the feed water.

To prevent galvanic action, zinc slabs should be placed in metallic contact with several of the boiler plates.

The Removal of Hardness.—No definite rule can be laid down as to whether it is desirable to remove the hardness from a boiler feed water. Impure feed water is bad for all boilers, and so much depends upon the analysis of the water, the type of boiler, and the evaporative power, that it is impossible to decide what is best to be done without knowing these particulars.

The cost of boiler feed water is in nearly every case quite small compared with the cost of converting it into steam. Water can be obtained in most cases at a cost below 1s. per 1000 gallons, while the cost of converting this amount into steam, taking the cost of fuel at 20s. per ton, and the evaporative power of 1 lb. of the fuel at 10 lbs. of water, would be about 9s.

On small plants consisting of one low-power boiler of the Cornish or Lancashire type, the water may be conveniently treated in the boiler by the addition of suitable reagents, or a feed heater may be installed to heat the feed and remove some of the scale-forming salts. The most suitable general reagents for introducing into a boiler are washing soda and caustic soda, these will partly prevent the formation of hard scale and neutralise any acid in the water.

With plants using 500 gallons per hour and upwards, it is undoubtedly economical to remove the impurities from the water, and it is unquestionably better to treat and purify the water before it enters the boiler.

No reagents or chemicals can be suitable for all waters, and each treatment requires consideration after an analysis of the water has been made and the general conditions taken into account.

The majority of modern water softening plants are of the two-solution type, in which the reagents are soda ash and lime, the variation in these types being the use of a saturated solution of lime water, and the use of milk of lime; the milk of lime method is, however, fall-

ing into disuse, owing to the difficulty of adjusting the required quantity of lime for precipitation.

Cost of Treatment.

The initial cost of water-softening plants is approximately £200 per 1000 gallons per hour, the smaller plants costing less per unit than the large ones.

Table 26 (on next page), compiled by Messrs. Mather & Platt, gives a good idea of the cost of reagents.

Chemical Treatment of Water.

The following formulæ show the various chemical reactions which occur in treating water for temporary and permanent hardness:—

Softening Water with Temporary Hardness.—The temporary hardness in water can be removed by boiling. This is too uneconomical to be carried out in practice for regular boiler supply, and therefore a chemical method is usually adopted. The action due to boiling the water can be expressed thus:—

$$\left.\begin{array}{c}\text{Calcium}\\\text{bicarbonate}\end{array}\right\} = \left\{\begin{array}{c}\text{Calcium}\\\text{carbonate}\end{array}\right\} + \left\{\begin{array}{c}\text{Carbon}\\\text{dioxide}\end{array}\right\} + \left\{\text{Water}\right.$$

$$CaH_2(CO_3)_2 = CaCO_3 + CO_2 + H_2O$$

By the chemical process, the calcium carbonate ($CaCO_3$) is precipitated by adding slaked lime (calcium hydrate $Ca(OH)_2$), giving the reaction:—

$$\left.\begin{array}{c}\text{Calcium}\\\text{bicarbonate}\end{array}\right\} + \left\{\begin{array}{c}\text{Calcium}\\\text{hydrate}\end{array}\right\} = \left\{\begin{array}{c}\text{Calcium}\\\text{carbonate}\end{array}\right\} + \left\{\text{Water}\right.$$

$$CaH_2(CO_3)_2 + Ca(OH)_2 = 2CaCO_3 + 2H_2O$$

By adding more calcium hydrate the carbonate of magnesia is further changed into hydrate of magnesia. The equation representing its removal is:—

$$\left.\begin{array}{c}\text{Magnesium}\\\text{carbonate}\end{array}\right\} + \left\{\begin{array}{c}\text{Calcium}\\\text{hydrate}\end{array}\right\} = \left\{\begin{array}{c}\text{Magnesium}\\\text{hydrate}\end{array}\right\} + \left\{\begin{array}{c}\text{Calcium}\\\text{carbonate}\end{array}\right.$$

$$MgCO_3 + Ca(OH)_2 = Mg(OH)_2 + CaCO_3$$

Softening Water with Permanent Hardness.—The permanent hardness is generally removed by the addition of sodium carbonate, the reactions being:—

$$\left.\begin{array}{c}\text{Calcium}\\\text{sulphate}\end{array}\right\} + \left\{\begin{array}{c}\text{Sodium}\\\text{carbonate}\end{array}\right\} = \left\{\begin{array}{c}\text{Calcium}\\\text{carbonate}\end{array}\right\} + \left\{\begin{array}{c}\text{Sodium}\\\text{sulphate}\end{array}\right.$$

$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4$$

$$\left.\begin{array}{c}\text{Magnesium}\\\text{sulphate}\end{array}\right\} + \left\{\begin{array}{c}\text{Sodium}\\\text{carbonate}\end{array}\right\} = \left\{\begin{array}{c}\text{Magnesium}\\\text{carbonate}\end{array}\right\} + \left\{\begin{array}{c}\text{Sodium}\\\text{sulphate}\end{array}\right.$$

$$MgSO_4 + Na_2CO_3 = MgCO_3 + Na_2SO_4$$

TABLE 26.—SHOWING THE CHARACTER OF WATER FROM VARIOUS SOURCES AND THE DIFFERENCE IN COST OF SOFTENING.

SOURCE	Well.	River.	River.	River.	Canal.	Well.	Brook.	Well.	Disused Shaft.	Clay Pit.
	GRAINS PER GALLON.									
Calcium carbonate (*carbonate of lime*)	10	8·74	13·15	16·39	10·99	9·19	2·06	9·41	8·3	1·39
Magnesium carbonate	4·76	2·78	·33	·31	2·76	1·4	·94	1·	2·82	1·78
Sodium carbonate	4·19	—	—	—	—	—	—	—	—	—
Calcium sulphate (*sulphate of lime*)	—	3·26	—	4·3	2·99	12·17	47·34	22·91	40·61	54·14
Magnesium sulphate	—	—	1·96	1·28	12·41	7·05	5·7	15·9	22·25	22·46
Sodium sulphate	4·15	1·44	·3	—	18·96	—	9·98	—	2·65	28·96
Magnesium nitrate	—	—	—	—	—	13·69	—	11·5	—	—
Sodium nitrate	—	—	·96	small	—	—	—	—	small	—
Magnesium chloride	—	—	—	—	—	·64	—	2·08	—	—
Sodium chloride	1·65	2·72	2·06	3·05	5·28	6·3	6·77	5·05	6·35	5·28
Silica	—	·43	·39	·42	·31	·62	·62	·9	·84	·36
	24·75	19·37	19·15	25·75	53·7	51·06	73·41	68·75	83·86	114·37
Total lime (CaO)	5·6	6·24	7·36	10·95	7·39	10·16	20·64	14·7	21·39	23·07
,, magnesia (MgO)	2·28	1·33	·81	·58	5·48	7·02	2·36	9·82	8·81	8·38
CALCULATED HARDNESS (i.e. *total lime and magnesia calculated to carbonate of lime*)	15·65	14·5	15·16	20·99	26·77	35·53	42·7	50·57	60·02	61·95
Approximate cost of chemicals required for softening 1000 gallons	0·2d.	0·5d.	0·4d.	0·6d.	1·2d.	2d.	2·8d.	3·1d.	3·6d.	4·2d.

NOTE.—*The above estimates of cost are based upon the following prices, viz.* :—

Quicklime . . . £1 per ton. | 58 per cent. Alkali . . . £4 per ton.

Feed-water Regulators.

When a large number of boilers of the water-tube type are in use, it is common to fit to each boiler some form of feed-water regulator. To ensure that the water will be maintained at a regular level, even when the load varies considerably, it is necessary that the feed regulator should be of simple construction, with an almost entire absence of friction, be certain in its action, and constructed so that it can be easily and quickly adjusted.

The Babcock & Wilcox regulator consists of a hollow cylinder, which is rotated on its axis by means of a float and lever placed inside the boiler. The cylinder has parts cut diagonally along its walls, and works in a liner having corresponding parts. The liner is fitted in a casting or box which is attached to the boiler shell, and has one

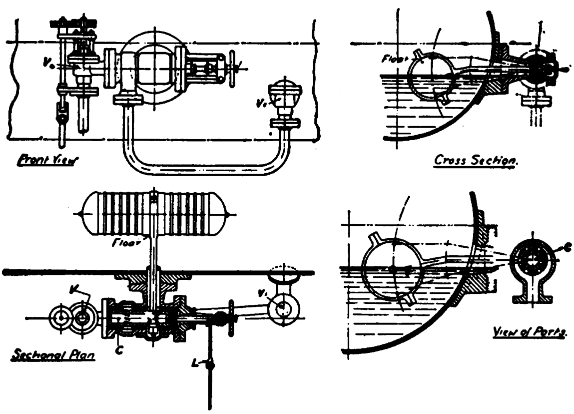


FIG. 187.—Feed water regulator.

branch for a feed-check valve, and another branch for a pipe leading to a non-return valve on the boiler drum.

The cylinder is moved lengthways along the liner by means of a suitable adjusting screw and spindle, the spindle being connected to the cylinder by ball bearings, so that friction is reduced to a minimum.

Attached to the spindle, between the adjusting wheel and the gland, is a lever and rod, the latter extending to a position in the stokehold, where it can easily be worked by hand from the firing level. The object of this rod and lever is to enable the stoker to ascertain that the float is moving freely when getting up steam, or to keep the float in the open or shut position, should the circumstances so demand.

The action of the apparatus, which is shown in Fig. 187, is as follows : The feed water enters by feed-check valve V into the hollow cylinder C, and, if the water in the drum is low, passes through the

ports of both cylinder and liner to the valve-box, whence it travels through the pipe and non-return valve V_1 into the boiler.

The position of the cylindrical valve is entirely regulated by the float in the boiler. When the level of the water in the boiler is low, the ports will be open, and as the water rises in the boiler and carries the float with it, the cylindrical valve will be moved round and the ports gradually closed. If the apparatus be kept clean and in good condition, the friction of all the working parts thereby being reduced to a minimum, it will be sensitive enough to keep the openings of the ports such as will just maintain the water at a uniform level; at any rate, there should never be a difference of more than 1 to $1\frac{1}{2}$ inches in the water level during the time the regulator is in action, and there should be no appreciable variation in the sensitiveness of the regulator when the boilers are worked at a high or low rate of evaporation, or even when the rate is changed suddenly.

The height of the level of the water in the boiler can be maintained at the position desired by moving the cylinder lengthways along the liner. This is done by turning the hand-wheel of the spindle attached to the cylinder, the travel of which, as the ports in both cylinder and liner are placed diagonally, will ensure an alteration in the point of cut-off relative to the position of the float.

It is usual with water-tube boilers to work with from 4 to 6 inches of water showing in the gauge glass, and the position of the regulator on the drum, and of the float, can be so arranged that when the valve is in mid-position, the required height of water will be regularly maintained, and any desired alteration of water level in either direction can be effected by the adjustment of the hand-wheel on the spindle.

A suitable indicator is provided on the adjusting wheel showing which way it should be revolved for the higher or lower water level, and there is also an indicator on the spindle itself showing when the valve is at the highest, lowest, or any intermediate position.

The main points to be observed to ensure the satisfactory working of the regulator are as follows:—

Cylinder.—The cylinders should fit in the liner so that it can be turned round by hand, but not be loose enough to be shaken.

Gland.—The gland on the adjusting spindle should be packed just sufficiently to keep it free from leakage, and this packing should be examined periodically and renewed when necessary.

Joints.—Owing to the variable temperature to which the regulator is exposed, the joints should be properly faced, and very carefully made.

Ball Bearings.—When the spindle and cylinder are taken out

for examination, great care should be exercised in collecting and replacing the balls in the bearings.

Feed-check Valve.—It should be borne in mind that when a boiler is laid off, the boiler-check valve should be shut, otherwise owing to the slight leakage due to the necessary clearance between the cylinder and the liner, the water will gradually find its way through the regulator, and the level be raised accordingly.

The pressure in the boiler feed pipes should not exceed $1\frac{1}{2}$ times the working pressure of the boiler, and the ratio between the steam and water cylinders of the feed pumps should be arranged accordingly.

CHAPTER XI.

BOILER DRAUGHT.

BOILER draught for supplying fuel with the necessary amount of air required for its combustion, is produced either by natural or mechanical means. In either case a chimney or funnel is required in order to produce, or help to produce, the difference in pressure of the air on the top and bottom sides of the fire-bars, and at the same time perform the important function of carrying away the waste products of the fuel combustion.

A chimney produces draught because the products of combustion in the flues and chimney are at a higher temperature, and therefore lighter than a corresponding volume of the air surrounding the chimney. The air pressure in the chimney being lower than that of the outside air, it is obvious that the gases in the flues and chimney will be displaced by air rushing through the fire-bars, to take the place of the gases escaping from the chimney.

The height and diameter of a chimney may be governed by any of the following conditions:—

1. The total amount of fuel consumed.
2. The composition and character of the fuel.
3. Type of boiler.
4. Local bye-laws and surroundings.
5. Height above sea level.

1. The total amount of fuel consumed in a boiler or boilers will have an influence on the area of a chimney, while the amount of fuel burnt per sq. foot of grate area, by natural draught, will determine its height. A Lancashire boiler with a chimney of ordinary height, say 100 feet, and burning steam coal, will satisfactorily consume about 20 lbs. of fuel per sq. foot of grate surface. With a chimney 300 feet high, as much as 85 lbs. per sq. foot could be burned; but this is unusual. Under normal conditions, 30 lbs. per sq. foot is the maximum for Lancashire boilers working under natural draught.

2. The character and composition of the fuel that is being burned determines to some extent the height of a chimney. The draught pressure to consume efficiently such fuels as coke or coal breeze is con-

siderably greater than that required for good steam coal. Anthracite and small bituminous coal require a draught pressure of from 1·1 to 1·8 inches of water to ensure satisfactory working, while good steam coal can be efficiently burnt with from 0·4 to 0·7 inch of pressure.

3. The particular design of a boiler often determines the type of chimney, which may in turn limit the height and area. Locomotive, vertical, and some water-tube boilers require special chimneys. Boilers adapted for the use of any form of forced draught allow of considerable modification in chimney area and height, and will give a much higher rate of combustion per sq. foot of grate surface than can be obtained with natural draught.

4. The height of a chimney is usually governed to some extent by local conditions and bye-laws, and also by its surroundings. In most localities it is necessary that the height shall be such as to prevent smoke becoming a nuisance and a danger to health. In towns having a fairly large population, the minimum height for a factory chimney is 80 feet. High buildings or other obstructions will sometimes need special consideration when planning the position and height of chimneys.

5. The base height above sea level, and the temperature of the atmosphere, often have to be taken into consideration, especially when boilers are being installed in countries where extremes of heat and cold are met with. The weight of the air changes with the height above sea level, and at 3½ miles above that level, the weight is reduced by one-half.

Draught Measurement.

Chimney draught is commonly measured by means of a U tube, seen at Fig. 188. This tube is fitted to a wooden case, and is provided at the back with a movable wooden scale graduated in inches and tenths of an inch. The tube is half-filled with coloured water, bringing the levels in line with the zero mark in the centre of the scale. One leg of the glass tube is connected by means of a flexible tube to an iron pipe leading to, and projecting into, the base of the chimney. Atmospheric pressure acts on one surface of the water through a small hole in the brass cap A, and any difference in pressure between the air in the stokehold and the gases in the chimney is indicated by the depression of the water in one leg of the glass tube. The difference in pressure is read by taking the difference between the two water levels in inches and parts of an inch. To find the pressure in lbs. per sq. inch, the water pressure in inches is multiplied by 0·036.

Water Pressure.

The weight of a cubic foot of fresh water is 62·425 lbs., and if this amount is contained in a vessel with base measuring 1 foot square, then the pressure on its base will be 62·425 lbs. per sq. foot. The pressure per sq. inch in the same vessel would be 62·425 ÷ 144 = 0·433 lb.

The usual calculations for water pressure are based on a cubic foot of water weighing 62·5 lbs., in which case a cubic inch of water

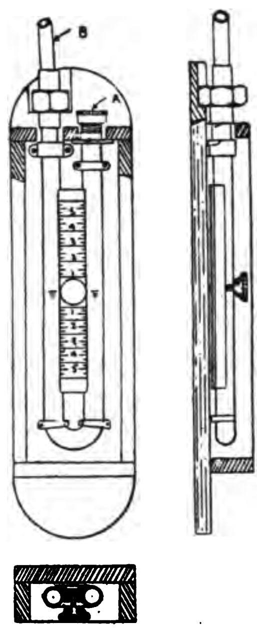


FIG. 188.—Draught gauge.

would weigh 62·5 ÷ 1728 = 0·036 lb. If a column of water of 1 sq. inch area is D_1 feet high, then the pressure on its base would be—

$$\frac{D_1}{144} \times \frac{62{\cdot}5}{1} = \frac{D_1}{2{\cdot}304} \text{ lbs.}$$

The pressure at the base of a column 1 sq. inch area and 1 inch high would be—

$$\frac{D_1}{2{\cdot}301} = \frac{1}{12} \times \frac{1}{2{\cdot}304} = \frac{1}{27{\cdot}648} = 0{\cdot}036 \text{ lb. or } 0{\cdot}576 \text{ oz.}$$

Calculations for Height.

It is undoubtedly uneconomical for the gases in a chimney to fall below 400° Fah., or to be much higher than 650° Fah. The amount of gas and air discharged from a chimney depends upon the height and area of the chimney, and the velocity of the escaping gases. The velocity increases nearly as the square of the temperature, and the intensity of the draught varies as the square root of its height. The velocity, however, reaches its maximum at about 600° Fah., and between 400° Fah. and 600° Fah. a difference of only 4 per cent. exists, therefore a temperature averaging 400° Fah. is the most economical. In actual practice an average temperature of 600° Fah. will more often be found, as that is considered to be a good working condition.

In laying out a complete steam plant, the general practice with Yorkshire boilers is to allow 2 sq. feet of grate to 1 sq. foot of outlet at the rear end of the furnace flues, and 2 sq. feet of furnace outlet to 1 sq. foot of chimney, or 4 sq. feet of grate to 1 sq. foot of chimney section. With these proportions of grate and chimney, the height in feet can be arrived at by cutting off the right-hand figure of the weight of coals in lbs. to be burned per hour.

As an illustration, if it is required to burn 900 lbs. of coal per hour, cut off the right-hand figure. The height of the chimney will therefore be 90 feet. If to burn 1200 lbs. of coal per hour, the height will be 120 feet.

With Lancashire boilers, the same rule as far as grate area to chimney section may be followed, but the height has to be increased about 12½ per cent. in comparison with the Yorkshire boiler to overcome the resistance of the contractions at the rear end of the furnace flues. If therefore a 9 feet diameter Yorkshire boiler is to be provided with a chimney to burn 1120 lbs. of coal per hour, the grate area 38 sq. feet divided by 4 gives chimney section 9·5 sq. feet and height 112 feet. With a Lancashire boiler 9 feet in diameter and 30 feet in length to burn the same quantity of coal per hour, size of grate 44 sq. feet divided by 4 gives 11 sq. feet of chimney section and 125 feet high.

Draught Power.

Natural draught power depends upon the height of the chimney and not upon its area. The weight of a cubic foot of air at 32° Fah. with an atmospheric pressure of 14·7 lbs. is 0·0807 of a lb. Then if the incoming air is at a temperature of 60° Fah. and the outgoing gases average 600° Fah., the weight of 1 cubic foot of each would be—

$$\text{Incoming air} \quad 0\cdot0807 \times \frac{32 + 461}{60 + 461} = 0\cdot0764 \text{ lb.}$$

$$\text{Outgoing gases} \quad 0\cdot0807 \times \frac{32 + 461}{600 + 461} = 0\cdot0375 \text{ lb.}$$

So that every foot of height above sea level of the fire grate gives a pressure on a sq. foot of 0·0764 − 0·0375 = 0·0389 lb., and the pressure per sq. inch would be 0·0389 ÷ 144 = 0·00027 lb. per sq. inch. To find the draught power of any chimney having an internal temperature of 600° Fah., and an external temperature of 60° Fah., multiply the height above grate level by 0·00027, and the result will be in lbs. per sq. inch. Thus the draught power of a chimney 150 feet high, and working under those conditions, would be 150 × 0·00027 = 0·045 lb. per sq. inch. To convert lbs. per sq. inch into inches of water pressure, divide the lbs. per sq. inch by 0·036, which, in the example taken, would give 0·0405 ÷ 0·036 = 1·12 inches of water pressure.

Rule for Draught Power of any Chimney.

Where the temperature of the incoming air and outgoing gases is not known, the following approximate rule can be used to find the draught power in inches of water. Rule: Height of chimney in feet multiplied by 0·0073 equals water pressure in inches.

Thus for a chimney 150 feet in height, the draught power would be 150 × 0·0073 = 1·095 inch of water pressure.

Approximate Height of Chimneys for Lbs. per Sq. Foot of Grate Surface.

Boiler	burning	18	lbs.	per sq.	foot	= 75	feet high.
,,	,,	26	,,	,,	,,	= 100	,,
,,	,,	35	,,	,,	,,	= 120	,,
,,	,,	40	,,	,,	,,	= 140	,,
,,	,,	50	,,	,,	,,	= 180	,,
,,	,,	60	,,	,,	,,	= 200	,,

Area of Chimneys.

The draught obtained from a chimney connected to several boilers is, as a rule, more constant than when connected to one boiler only, and it is owing to this fact that the area of the chimney can be relatively less. In a battery of several boilers it is not unusual for one or more to be laid off for cleaning purposes, and it is only on rare occasions that all boilers are called upon to work at their utmost capacity. In land boilers the area of the chimney can be found by the following formula, based on actual working conditions :—

Let A = Area of smallest cross-section of chimney in sq. feet.
G = Number of sq. feet of grate surface in all boilers.
W = Pounds of coal per sq. foot of grate surface per hour.
H = Height from fire-bars to top of chimney.
C = Constant varying with the number of boilers connected to the chimney.

$$\text{Then} \qquad A = \frac{G \times W \times C}{\sqrt{H}}.$$

The constant C is reduced according to the number of boilers, and where the flues do not exceed 150 feet in length, C is given by Hutton in "Steam-Boiler Construction" as 0·1 for a chimney with one boiler, 0·085 for from two to six boilers, 0·075 from six to eleven boilers, and 0·065 for a battery of twelve or more. Example: A Lancashire boiler having a fire-grate surface of 45 sq. feet, and burning 20 lbs. of coal per sq. foot with a 100 foot chimney :—

$$G = 45.$$
$$W = 20.$$
$$H = 100.$$
$$C = 0{\cdot}1.$$

$$\text{Then} \qquad A = \frac{45 \times 20 \times 0{\cdot}1}{10} = 9{\cdot}0 \text{ sq. feet.}$$

For a battery of twelve boilers :—

$$A = \frac{45 \times 20 \times 12 \times 0{\cdot}065}{10} = 70{\cdot}2 \text{ sq. feet.}$$

Velocity of Chimney Gases.

The velocity of the gases escaping from a chimney is considerably influenced by the resistance offered by the fuel, and also by the friction due to their passage through the flues. Bends, angles, and narrow flues retard the passage of hot gases.

To find the theoretical velocity of chimney gases, let—

V = Velocity in feet per second of chimney gases.
g = Velocity acquired in one second by a body falling from a state of rest in a space devoid of air = 32·2 feet per second.
h = Height of chimney.
T = Absolute temperature inside chimney.
t = " " outside "

$$\text{Then} \qquad V = \sqrt{2gh\frac{(T - t)}{T}}.$$

Example.—A Lancashire boiler with incoming air at 60° Fah., internal temperature 600° Fah., and a chimney height of 100 feet.

$$\text{The velocity} = \sqrt{2 \times 32{\cdot}2 \times 100 \frac{(1061 - 521)}{1061}} = 57{\cdot}2 \text{ feet per sec.}$$

Actual Velocity.

The actual velocity of chimney gases is considerably less than the theoretical rate, and can be found by the following empirical formula :—

$$V = \frac{(T - t) \times 8 \times \sqrt{H}}{T \times 3{\cdot}3}.$$

Where V = Velocity of chimney gases in feet per second.
T = Internal temperature of chimney.
t = Temperature of incoming air.
H = Height of chimney.

Example.—A Lancashire boiler, internal temperature of chimney 600° Fah., incoming air 60° Fah., height of chimney 100 feet.

$$\text{Then} \quad V = \frac{(600 - 60) \times 8 \times 10}{600 \times 3{\cdot}3} = 21{\cdot}8 \text{ feet per second.}$$

Draught Control.

In order that the rate of fuel consumption may be governed, damper gear is fitted to the main flues of the majority of land boilers. Many devices are in use for controlling the draught to the furnace, the object being to isolate the boiler from the chimney, and thus wholly or partly stop the draught acting on the fuel. The simplest form of damper consists of an iron plate sliding in vertical grooves, fitted to a convenient part of the main flue of the boiler. The sliding plate is operated upon from the front of the boiler by lifting or lowering an iron counter-balance weight, which is connected to the damper plate by means of a chain. By regulating the height of the damper the rate of combustion can be controlled ; thus if the boiler starts blowing off steam, the damper is lowered, whereas if the steam pressure drops, the damper is raised. Another form of damper, for use in the main flue, is one which swivels or rotates on a spindle in such a manner that a quarter turn will fully open or close it.

Many methods for keeping damper plates airtight are in use, and for the sliding type the best arrangement is probably that shown in Fig. 189. Here C is a cast-iron frame, the bottom part of which is let into the brickwork of the flue a distance of about 3 inches ; the

flange resting on the top allows of a good airtight joint being made with cement. The flange of this frame is fitted with a groove into which is pressed asbestos large enough to project. Casing B drops into the frame C, and makes a joint between B and C which is quite airtight. This casing forms a stuffing-box into which the gland A can be dropped. A ring of packing at the bottom of B is pressed up against the damper plate and makes an airtight joint. The stuffing-box B is prevented from lifting by four studs placed in the frame C.

A large number of automatic draught-controlling devices have been introduced within the last few years. Some of these simply aim at controlling the fuel combustion when the steam rises and falls, others are designed with the object of starting or stopping the mechanical stokers, and at the same time regulating the draught pressure.

Another method of damping or controlling the rate of combustion

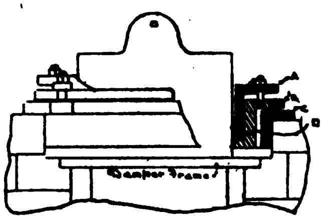


FIG. 189.—Method for keeping damper airtight.

is by means of draught plates fitted to the front of the ash-pits, and by the provision of grids to the furnace doors. The latter are particularly useful when bituminous coal is being burned, as with proper use, after charging the fire, the greater portion of the smoke can be usefully consumed.

Cost of Draught Power.

The temperature of the furnace gases in a Lancashire boiler furnace working under good conditions, with natural draught, would be about 2500° Fah., and if economisers were not in use, the chimney gases would be about 600° Fah.; therefore out of 2500° of heat generated by the fuel, about one-quarter escapes without doing useful work.

As an example of the cost of producing chimney draught, suppose a Lancashire boiler is supplying steam to a 300 horse-power engine, and to produce 1 horse-power the boiler burns 2 lbs. of coal; of this 2 lbs., 1½ lbs. is utilised in doing useful work, and the remaining ½ lb. is required for producing the draught. Thus of the total horse-power

developed by the boiler, 225 horse-power is doing useful work, and 75 horse-power is creating the chimney draft.

The heat carried off by the chimney gases can be found by multiplying the difference in the temperature of the internal gases of the chimney and the external air, by the specific heat of the air and the weight of the waste products of combustion.

Example.—If 20 lbs. of air are supplied per lb. of fuel, the weight of the chimney gases will be approximately 21 lbs. per lb. of coal consumed. Then if the difference in the internal and external temperatures is 540° Fah., the heat carried off will be $21 \times 540 \times 0{\cdot}238 = 2698$ B.T.U. Taking the calorific value of the fuel at 14,500 B.T.U., the cost of producing the chimney draught will be $2698 \times 100 \div 14500 = 18{\cdot}6$ per cent. of the total cost of the fuel.

Boiler Flues.

All boiler flues should be readily accessible, both for cleaning and in order to facilitate the examination of the shell plates. Flues are usually arranged so that the products of combustion on leaving the furnace tubes pass under the centre of the boiler, dividing at the front end, and flowing through the side flues towards the chimney. All flues should be as direct as possible, having only gradual changes of section where necessary, and without sharp bends.

Area of Boiler Flues.—The temperature of the gases leaving the flues varies between 300° Fah. and 650° Fah., according to circumstances.

When this temperature is known, the area of the boiler flue can be calculated by the following formula, based on a gas velocity of 1175 feet per minute:—

Let A = area.

T = absolute temperature of gases.

n = lbs. of coal consumed per hour.

$$\text{Then} \qquad A = \frac{nT}{144{,}000}.$$

Where several boilers lead into a common flue, the area of that flue, if calculated on the above basis, can be modified.

Artificial or Mechanical Draught.

The advantages derived from the use of mechanical draught are:—

1. Increase in the evaporative power of the boiler.
2. Capability of burning low grade fuel.
3. Reduced size of boiler for a given evaporation.
4. Economy in the use of fuel owing to better combustion.

5. Control of combustion and evaporation.
6. Smoke prevention and control.
7. Reduction of chimney height.

1. The addition to a boiler of some system of artificial draught gives a means of obtaining a greatly increased consumption of fuel per sq. foot of grate surface. As much as 150 lbs. of fuel has been burned per sq. foot of grate surface by the use of forced draught; this, however, is abnormal and uneconomical. The Scotch marine type boiler will economically burn up to 30 lbs. per sq. foot, the Lancashire 35 lbs., water-tube boilers of large tube type up to 40 lbs., small tube type water-tube boilers up to 65 lbs., and locomotive boilers up to 120 lbs. per sq. foot of grate surface.

2. By the use of forced draught very low grade fuel can be used for generating steam. Such fuel as coke breeze is frequently used as the only fuel for supplying a boiler with heat. Fuel that could not possibly be burned with natural draught can be effectively burned by mechanical means.

3. The evaporative power of a small boiler can be considerably increased by the addition of some method of supplying artificial draught. A considerable saving in floor space can be obtained thereby.

4. Forced draught allows of more complete combustion than can be obtained by natural means. The initial temperature of the fuel is higher, and therefore the transmission of heat is greater and more rapid. The efficiency must be increased.

5. Mechanical draught allows of a much better adjustment of air supply than is possible with natural draught. The air can be supplied in such quantities as to suit the fuel consumption to the best advantage.

6. For the above reasons the formation of smoke can be very largely overcome.

7. When using mechanical draught the chimney acts chiefly as a means of discharging the waste gases.

Artificial Draught Systems.

The systems used for mechanically producing draught come under two heads: Forced draught and Induced draught.

The term "forced draught" is applied to those systems of producing artificial draught which force the air into the furnaces. Induced draught is the name given to systems which draw air into the furnaces. The best-known methods of producing forced and induced draught are:—

Howden's System.—The principles on which the Howden's system of hot air forced draught is based, are the supplying under pressure of hot air for combustion in quantities suited to the quality of the coal being burned; and the utilisation of the heat in the waste gases for the purpose of raising the temperature of the air for combustion.

The apparatus used is a fan, driven by means of a steam engine, electric motor, or belt, which supplies the air for combustion, discharging it through a conduit round a series of tubes. The waste gases, after leaving the boiler, and before entering the uptake, pass upwards through these tubes in the air-heating chambers, thus giving up part of their heat to the air, which then passes along the passages into the airtight reservoirs surrounding the furnace front. From these chambers the air is passed through the furnace fronts by valves into the ash pits and over the fires, through air-distributing boxes in proportion exactly suited to the class of fuel being burned and the rate of combustion required, thus ensuring a good combustion of the fuel.

The fan used is of the centrifugal type, and can be run by any suitable type of engine. In the marine type boiler retarders are fitted, one in each boiler tube. In the furnace fronts the ash-pit air valves are operated by one handle, and a safety locking device is also fitted, which prevents the furnace doors from being opened until the ash-pit air valves are closed. The air pressure in the ash-pits varies from 0·375 to 0·1 inch of water pressure.

This system is suitable for use on all types of boilers, both land and marine. Fig. 190 illustrates its application to a Scotch marine boiler.

Meldrum's Forced Draught.—With this system all the air for combustion is delivered by blowers into airtight ash-pits under the fire-grates, whence it can only escape by passing through the mass of burning fuel. By regulating the valve controlling the steam supply to the blowers, the amount of air supplied to the ash-pits can be regulated according to the rate of combustion required. The steam consumption of the blowers varies according to the nature of the fuel being burned, but from 3 per cent. to 5 per cent. of the steam generated may be taken as an average consumption.

To prevent any risk of moisture finding its way into the flues of cylindrical boilers, the steam is dried before reaching the blowers by passing it through superheaters placed in the side flues.

Provision is made for preventing excessive smoke by the addition of a secondary air supply through a valve or door in the dead plate at

the front of the grate. The valve is opened automatically by the action of closing the door after firing, a thin stream of air being delivered over the fire which mixes with the green gases and assists in combustion. The valve is closed by knocking aside the lever which opened it, the lever falling automatically into position for the next opening of the valve.

Ellis and Eaves' System.—In this system a fan is placed in the uptake of the boiler or at the base of the chimney, the products of combustion being drawn towards the fan and then forced up the chimney shaft. A horizontal nest of tubes placed on the top of the boiler heat the incoming air; the furnace gases after leaving the furnace

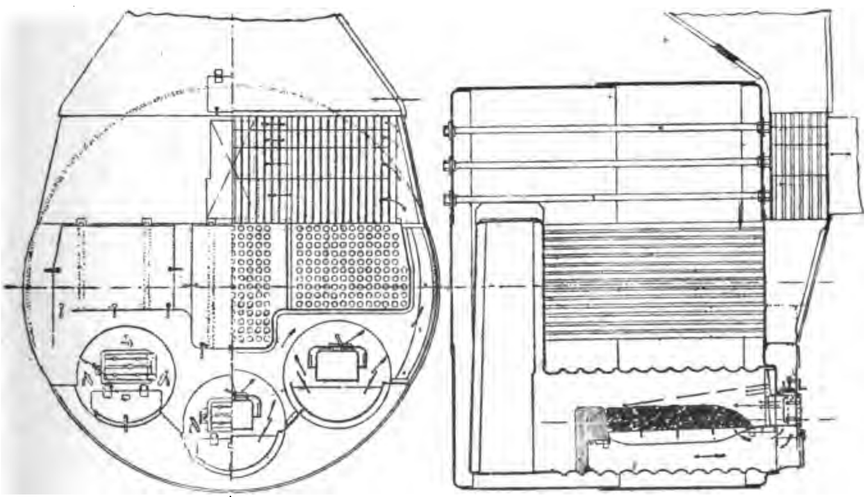


FIG. 190.—Howden's system of forced draught.

tubes pass round the outside of these tubes and convert them into a heater.

The flow of air is through the tubes and then downwards into the furnace, the waste gases being cooled to a temperature which does not seriously interfere with the working of the fan. The arrangement is shown in Fig. 191.

The following figures give the results of a trial taken on a marine type boiler with fuel having an evaporative value equivalent to 15·4 lbs. of water from and at 212° Fah.:—

Coal consumption per I.H.P. of engines per hour	1·02	lbs.
Combustible per I.H.P. per hour	·935	,,
Water evaporated per lb. of combustible from and at 212° Fah.	13·35	,,
Water evaporated per lb. of coal from and at 212° Fah.	12·23	,,

Closed Stokehold.—The closed stokehold system is the one most generally used in the Royal Navy. The boiler-room hatchways are covered in, and the funnel casings made airtight. Entrance to the stokeholds is obtained by means of air locks. Fans are arranged to

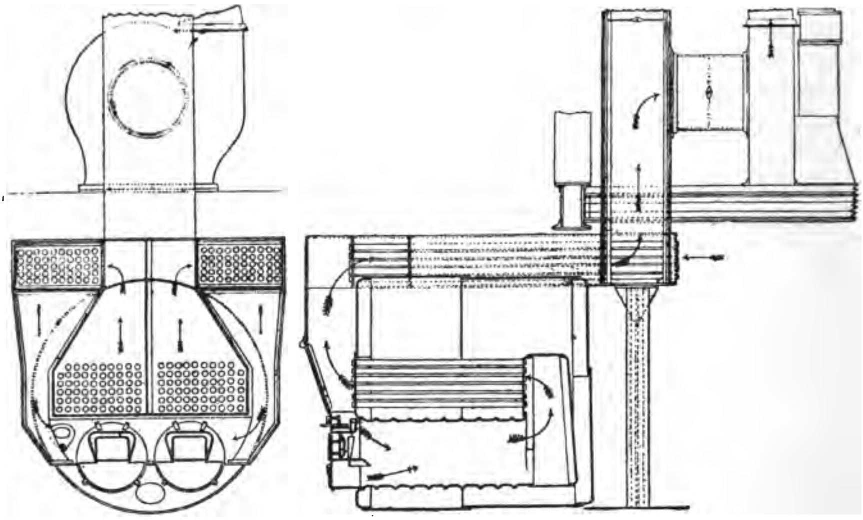


FIG. 191.—Ellis and Eaves' system of induced draught.

force air into the stokeholds, thus putting the whole of the boiler-room under pressure.

When water-tube boilers are in use in closed stokeholds, the air supply to the furnaces passes flap valves, which, in the event of a tube bursting, are closed by the rush of steam.

CHAPTER XII.

THE MANAGEMENT OF STEAM BOILERS.

THE first duty to be carried out by the engineer when taking charge of a boiler, or battery of boilers, is to ascertain and become thoroughly acquainted with the general construction of the boiler, the boiler mountings, and the pipe arrangement. If it is not possible to examine the internal parts, drawings should be consulted, and the thickness of the plates and tubes, methods of staying, size of tubes, and any other information of importance should be carefully noted.

Filling the Boiler with Water.—Before fires are laid in any boiler, it should first be filled with water to the working level, as indicated by the working level pointer, or in its absence to about three-quarters the height of the water-gauge glass; this will ensure there being sufficient water above the furnace crown or combustion chamber. Clean fresh water only should be used for this purpose. The actual filling of the boiler can generally be carried out by means of a hose led from the water supply to the top man-hole, or else by making use of the ordinary feed pump in the usual manner for boiler feeding.

Preparing Fires.—In order to prepare a furnace fire for lighting up, the fire-bars are first *primed* by placing a layer of average size coal (about the size of a man's fist) over the entire surface. On the front end of this layer of coal, oily waste, wood shavings, and firewood are placed, and it is *topped* with coal nearly to the furnace crown.

Raising Steam.—When it is necessary to start raising steam, the fire is started off by lighting the oily waste; when this has been done, the ash-pit doors are closed and the furnace doors left opened. By this means the fire will obtain a plentiful supply of air to aid in its combustion.

The time that should be taken in raising steam in a boiler depends on the type of boiler and the degree of urgency of the steam requirements. In every case steam should be raised as slowly as practicable. In cases where the boiler is provided with three furnaces, the bottom fire should always be lit up first, and after about two hours the wing fires should be lit. In another hour the bottom fire can be spread by

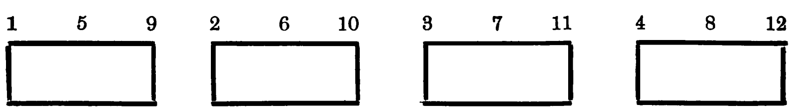
pushing the mass of burning coal back over the priming. The furnace door is then closed and the ash-pit door opened, thus admitting air to the ash-pit and to the underneath part of the fire-grate.

During the lighting up period, care should be taken to see that all air cocks are opened, as by doing that most of the air given off by the fresh water will be allowed a free exit, and so the boiler plates will escape the very corroding effect that the oxygen may have upon them.

When full steam is wanted, all fires are spread, but on no account should fires be forced until some steam is showing in the pressure gauge. When hydrokineters or some other methods of properly circulating the water in the boiler are fitted, then all fires can be lit at the same time. This will prevent the middle furnace getting hot before the others, and thus expanding out of proportion to the other furnaces. Great risk is taken when boiler furnaces are fired too rapidly, or while some of the water in the boiler is still cold. The evil of this proceeding can be seen when the question of expansion is considered. A rise in temperature of 180° Fah. causes steel to expand one-thousandth of its length, and as the top part of a boiler may be considerably hotter than the bottom, the top part would be expanding at a greater rate than the bottom part, and consequently great stresses would be set up. The grooving of boiler plates is mainly caused by expansion and contraction taking place, and may be to a considerable extent due to the too rapid lighting up and steaming of the boiler.

Firing the Boiler.—A regular system of firing should always be adopted, and the utmost regularity observed. Each furnace should be fired in regular rotation according to a recognised system. When firing, each furnace door should be quickly opened, and the moment the coal is spread it should be immediately closed. The thickness the fire should be kept depends upon the circumstances under which the coal is being burnt, the rate of combustion, and the type of boiler; but whatever the amount of coal being burnt, the thickness of the fire should be maintained as constant as possible, and all air spaces and holes should be immediately filled up.

To regulate the firing of a battery or set of boilers, it is usual to fit some mechanical or electrical device. This is generally fitted in the engine-room, and is made so that it can be adjusted to ring a bell in any stokehold every given number of minutes. When four boilers are placed in a line, it is usual to number the furnaces in this order :—



Only one furnace is fired at a time, two men working together, one putting on the coal, the other opening and shutting the door.

The rate of evaporation of the water in a boiler depends upon the amount of heat transmitted to the water from the fire, and the rate of the transmission of the heat depends upon the difference of the temperature on either side of the boiler plates. The fireman judges his fire by its colour and general appearance, and in order to give some idea of the temperatures obtained on the surface of the fire, the following approximate temperatures are given :—

Colour	Dull Red,	Approx.	Temp. Fah.	1250°
,,	Cherry Red	,,	,,	1450°
,,	Bright Red	,,	,,	1650°
,,	Orange Colour	,,	,,	2000°
,,	White Heat	,,	,,	2250°

Cleaning Fires.—All fires should be cleaned periodically, the length of time between each operation being determined by the nature of the fuel and the circumstances under which it is being consumed. Only one fire in each boiler should be cleaned at one time. On commencing to clean fires, the feed check should be partly closed on the boiler which is being cleaned, and the ash-pit door shut ; the live coal on one half side of the furnace is pushed over to the other side by means of the slice or rake, and then all the dirt and clinker is raked out. The live coal is then pushed back on to the bare bars, and the other half of the furnace is then cleaned. When this has been done, the live coal that is left will be sufficient to spread over the whole of the bars and kindle the fresh fuel put on. If cleaning is done smartly, the fire will burn up without unduly cooling the furnace.

Boiler Accessories.—Fig. 192 illustrates a set of boiler accessories. A is a single fire-bar, B double fire-bar, C Admiralty pattern fire-bar, D slice-bar, E pricker-bar, F rake, and G a tube stopper.

Attention Required while Steaming.—During the time any boiler is under steam, constant attention should be paid to the height of water showing in the gauge glass, and the gauge cocks should be frequently tested. Many furnace crowns have come down owing to shortness of water, which has often been attributed to a false water level showing in the gauge glass, but which on examination has been found to result from the choking of gauge fittings. Safety valves should occasionally be tested by lifting them slightly off their seatings ; this will ensure they are not stuck in any way and are quite free to lift if required.

Low Water.—Many explosions have been caused in boilers by

the overheating of furnaces due to shortness of water. In most cases this is brought about by insufficient attention being given to the height of the water showing in the gauge glass, and to the neglect of gauge fittings. Other contributory causes may be defective feed valves, stoppage of feed water, leaky blow-off cocks, great density, bad fusible plugs, and failure of low-water alarms.

In cases of low water, precise and definite directions as to what should be done cannot be given, because circumstances vary. It is, however, now generally agreed that the rapid cooling of a red-hot plate is not in any way detrimental to the metal. The steel used in the manufacture of modern boiler furnaces can be heated to its hardening point and dipped in cold water without its having any bad effect on the

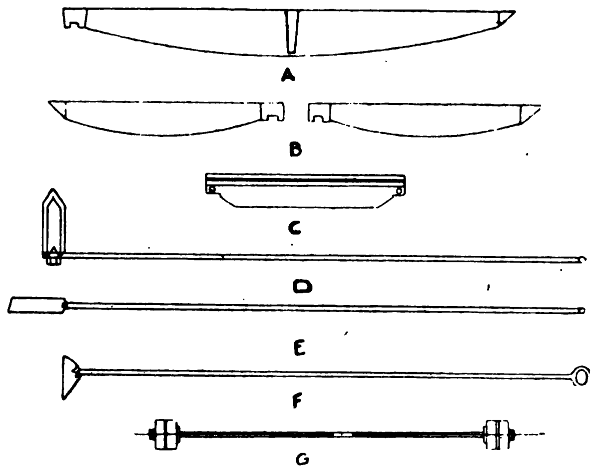


FIG. 192.—Boiler tools and accessories.

plate. Therefore, in cases of low water, the feed should be immediately turned on to the full extent, the dampers closed, the furnace doors opened, and the safety valves slightly eased off their seats. Drawing fires on boilers short of water must always be attended with some danger, and when the plates show signs of overheating should not be done, as the heat of the furnace may be greatly intensified by doing so. When a bright heavy fire is being carried, it can be damped down by means of wet ashes or small fresh fuel.

Surplus of Steam.—When safety valves are lifting owing to excessive pressure, dampers and ash-pit doors should be closed and the amount of feed increased. With tubular boilers, the smoke-box doors can be eased, and if a silent blow-off is fitted, that also can be very slightly opened.

Priming.—Priming is the violent ebullition of the water in the boiler, and is said to occur when an undue amount of water or moisture is carried away from the boiler with the steam.

Priming is always likely to occur if the boiler is forced beyond its normal capacity, or if the engines are suddenly started and the steam taken away more rapidly than it is being generated, causing the steam pressure to fall more quickly than the temperature of the water in the boiler. When water in a Cornish or Lancashire boiler is allowed to get much above working level, the area of the water surface is reduced, and this results in a more violent ebullition of steam. A high water level also reduces the available steam space, which tends to cause priming. Another source of this trouble is bad or greasy feed water; this also produces violent ebullition on the surface of the water.

In the event of boilers priming, the speed of the engine should be checked, the separator drains and cylinder reliefs opened, and the dampers closed. If the probable cause is dirty or greasy water, then the blow-down valve or scum cock should be used frequently.

When only one boiler in a battery is found to prime, then it may be caused through the stop valve being opened too wide, and can be overcome by closing the valve a turn or two.

Blowing down.—The number of times a boiler should be blown down depends upon the state of the feed water. If the boiler is fed with water from an evaporator, and the density is normal, no blowing down is necessary. When water is used having several degrees of hardness, then blowing out about half an inch of water, at least once a day, will get rid of some of the sediment.

Should salt be present in the boiler owing to a leaky condenser tube, then blowing down should be continued until the boiler water shows not more than $3\frac{1}{2}/33$ or $17\frac{1}{2}$ oz. of solid matter to the gallon.

Banking Fires.—The advantage of banking fires instead of drawing them lies in the fact that the boiler is kept at a good even temperature, and that steam can be raised quickly, without unduly straining the boiler plates.

The method adopted is for the fire to be first cleaned, then pushed back to the bridge and completely covered with fresh fuel, the dampers and ash-pit doors being closed and the furnace doors opened. The precaution of seeing plenty of water in the gauge glass should always be taken, and if considered necessary the safety valves should be eased.

It is estimated that about the same amount of coal is used in banking a boiler for twenty-four hours as would be required to raise steam from cold water.

Manholes.—Before removing any manhole it is always advisable to lift the safety valve and keep it raised for some time; this will relieve any pressure or destroy a vacuum. A large number of accidents have been caused by doors being blown off, escape of boiling water, or by the atmospheric pressure pushing the attendant violently on to the manhole opening.

Idle Boilers.—Many accidents have occurred by steam being inadvertently admitted to boilers in which men are working, and every precaution should be taken to prevent accidents of this character. All stop valves, feed cocks, safety valves, and blow-down cocks, which can possibly admit steam or water to the boiler, should be securely shut, and precautions taken to see they are not opened by mistake.

Boilers not required for immediate use should be thoroughly cleaned, filled with alkaline fresh water, and not opened until required. Another method of preserving boiler plates and preventing internal corrosion in idle boilers is first for the boiler to be thoroughly dried by means of an airing stove, and then all doors jointed up with the exception of the lower manhole door. Through the latter opening perforated trays of burning charcoal are placed. This will consume the oxygen and prevent corrosion, and if unslaked lime is also introduced it will absorb any moisture or carbonic acid which may be present. About ½ cwt. per furnace of unslaked lime will be found sufficient.

Explosions in Boiler Flues.

Explosions of collected gases in the external flues of boilers have been known to occur. They may be caused, when a boiler is standing under banked fires, by the accumulation of an explosive mixture of air and gas, which is due to insufficient draught.

When very small fuel is being used, an explosive mixture may pass to the flues, because the air for combustion is unable to pass freely through the mass of fuel, and complete combustion in the furnace.

Flue explosions will not take place if firing is carried out in a systematic manner, and proper attention is paid to the regulation of the damper and air supply.

In a boiler having more than one furnace, the possibility of flue explosions will be almost entirely eliminated, if one of the fires is kept bright and free from fresh fuel.

Particular attention should be paid to a boiler under banked fires, especially when it forms one of a battery of boilers, some of which are

under full steam pressure. The damper of all standing boilers should be left slightly open.

Cleaning and Preparation for Inspection.—The frequency with which a boiler should be cleaned and scaled will depend upon the accumulation of scale, grease, or salt, and the judgment of the engineer. When a good type of feed heater and filter is fitted, a boiler can be steamed for several months without danger from overheating, or without great loss in efficiency; but when heaters and filters are not used, the formation of scale cannot be prevented; then the boiler should be scaled as often as possible. The average time for a Lancashire or Cornish boiler is about three months. A water-tube boiler requires cleaning every twenty-one days.

The common method of removing scale is by means of the chipping hammer; this is frequently a long and laborious task, especially when the scale is very hard. It will often be found possible to soften the scale by adding soda to the feed water for about twenty-four hours before opening the boiler. The soda converts the sulphate of lime into carbonate of lime, and this has the effect of loosening the scale. Directly the boiler is empty, and before the atmosphere has had time to harden the scale, cleaning should be commenced with wire brushes and scrapers, and by using the hose-pipe to wash down.

As scale hardens after being in contact with air for two or three hours, a good method for removing the scale is to blow the boiler down at a low pressure, allow it to cool, and keep all manhole doors on until ready for cleaning. Or the boiler can be allowed to cool with the water in it, and the scale scraped off as the water level is lowered.

For the removal of grease, naphtha will be found to be of great use, but if a small amount of scale is allowed to form immediately the boiler is closed up, the grease will often come away at the same time as the scale.

Note.—Safety lamps must in all cases be used if naphtha is taken into a boiler.

Cleaning Water-tube Boilers.

For cleaning the tubes of water-tube boilers, special appliances are generally necessary in order to remove the soft sediment. A wire brush fitting tightly in the tube can be used. When the scale is hard, special scrapers, boring bars with adjustable cutters, or even turbine cleaners worked by water pressure, are required, in order properly to clean and free the tubes from scale.

In addition to cleaning the internal parts of a boiler, it is most

important that all external parts should be thoroughly brushed with a wire brush, scraped clean and dried.

When opening a boiler out for inspection, the fire-bars, bridge, and any brickwork or covering that will prevent the proper examination of the boiler should be removed.

Boiler Inspection.

Every boiler should undergo a thorough inspection by a competent engineer experienced in boiler work at least once every twelve months, and unless this is carried out in a proper manner, both internally and externally, no good purpose is served. The inspection should include the examination of :—

I. The safety valves, steam and water gauges, stop valves, blow-down cocks, air and try cocks.
II. The feed valves, feed pipes, scum pipes, and slits in the internal steam pipes.
III. The fire-box, tubes, and tube plates for symptoms of cracks, laminations, burning, bulging, blistering, thinness, leaks, deformation or other signs of weakness.
IV. The seams, joints, and rivets, both internally and externally, for corrosion, pitting, and leakage.
V. All stays, stay bolts, and stay tubes for corrosion and pitting.
VI. The flanges of plates, angle rings, and front plates for cracking and grooving.
VII. Fusible plugs, man-hole and mud-hole doors.
VIII. Boiler seatings and shell plates for leakage, corrosion, and dampness.

The examination of a boiler should be done in a systematic manner; notes and sketches should be made if necessary. In all cases where a considerable amount of pitting is found, the plate should be drilled and tested for reduction of thickness.

After examination, the boiler should be subjected to a hydraulic test; to do this all manhole joints are made, safety valves weighed down, and the boiler filled with water and connected to a hydraulic pump. If possible water heated to about 200° Fah. should be used, and a pressure equal to not less than 50 per cent. above working pressure applied after the boiler has had time to become sufficiently warm to produce a uniform expansion of the boiler plates. During the time the pressure is on the boiler, the seams, stays, rivets, and joints should be examined for leakage; flat surfaces should be tested with a straight edge; gauges should be fixed and adjusted in the furnace and com-

bustion chambers to test for distortion, and any change of form which points to weakness should be duly noted.

When the pressure is relieved, then a thorough examination should be made for signs of permanent set, distortion, and weakness.

Corrosion, Pitting, and Grooving.

We have already explained (p. 241) that corrosion may be due to

I. Impure feed water.
II. Air.
III. Animal and vegetable oils.
IV. Galvanic action.

The obvious remedy for impure feed water is, first, by filtration, or by some method of mechanical purification, to eliminate all suspended matter such as clay, mud, grit, animal and vegetable matter, and micro-organisms, then chemical purification, to remove the dissolved impurities, both organic and disorganic, and at the same time eliminate the gases.

A great number of efficient filtering and purifying plants are on the market, but without some knowledge as to the amount of water it is desired to treat, advice on the subject is of little use. When, however, the boiler feed water is tested and found to be acid, a solution of carbonate of soda should be added to the feed until the water just turns red litmus paper blue. After treatment with carbonate of soda lime can be added at the rate of 1 lb. per 500 h.p. developed. This should be sufficient to keep the water in an alkaline state.

To overcome the trouble due to having air in the boiler, the feed water should be heated to as high a temperature as possible. By that means a good deal of the air will be liberated. The feed pipe should be nearly the full length of the boiler, with slits arranged in the pipe for feed delivery. This allows the feed water to be further heated before actually being delivered into the boiler.

All pump rods should be kept tight, and the hot well tank should be arranged to deliver under pressure to the feed pump.

The presence of grease in boilers is mainly due to the use as feed of condensed steam, or to the heating of the feed water by exhaust steam.

To overcome the troubles which may be caused by grease being present in a boiler, the following rules should be observed :—

(i) Use oil very sparingly on piston and valve rods.

(ii) Use graphite in place of oil for lubricating cylinders and valve chests.

(iii) Use the best hydrocarbon oil for rods.
(iv) Have a good feed water filter fitted.

It has been proved that zinc and iron, if placed together in aerated water, but without touching each other, will both corrode; if iron wire be attached to the iron and zinc, then only the zinc corrodes.

Internal corrosion by galvanic action should be counteracted by suspending zinc slabs in convenient parts of the boiler, or by placing the zinc in metallic contact with stays or plating.

Grooving has been eliminated in most modern boilers. The cause is chiefly due to the expansion and contraction of the furnace tubes coming on a front plate which is too stiffly stayed. If the expansion and contraction can be taken by the front plate breathing, then no harm is done; but if the plate is strongly supported by having gusset stays riveted close to the furnace tube, then grooving will probably take place, either in the root of the end plate, or at the root of the angle iron or flanging of the furnace to the end plate, or over the top of the angle iron on the end plate.

This trouble of grooving has been remedied in some boilers by removing the bottom rivets of the gusset stays, and thus allowing more freedom for breathing. The breathing space is the space between the furnace crown and the gussets, and in Lancashire and Cornish boilers this space should be so proportioned as to allow for longitudinal expansion of the furnace tube. Another method adopted is to fit link stays. These are arranged in the same manner as gusset stays, but the plate is replaced by links in the ends of which pins are fitted to connect the plates riveted to angles.

Preservation and Working of Water-tube Boilers.

The following instructions are issued by Messrs. Yarrow for the preservation and working of their water-tube boilers :—

Precautions when Lying Up.—For the better preservation of a water-tube boiler when lying up, it is advisable that it should be emptied and drained of water, and thoroughly washed out internally with clean fresh water. Any accumulation of soot or ashes should be removed from the tubes and tube plates. This is of the utmost importance, because if moisture becomes absorbed by the dirt which collects on the heating surfaces, corrosion will soon commence, and, when once started, will increase rapidly. The casing should be carefully swept on the inside. After being thoroughly cleaned, the outside of the tubes at the lower end should be sprayed with tar from time to time so as to give them a good protective coating.

Drying Boiler.—A small coke fire should be lit in a suitable portable receptacle, which may be placed in the furnace to thoroughly dry both the inside and the outside of the boiler, the coke fire to be kept far enough from the tubes to avoid overheating them; in the case of a boiler burning coal, the coke fire should be placed in the ash-pan and a few fire-bars removed. The manhole, mudhole, and casing doors being off, the vapour formed will escape.

A paraffin flare lamp or electric heater is preferable to a coke fire, as the sulphur from coke causes corrosion unless care is taken to obtain coke free from sulphur.

Internal Examination.—When the boiler is dry, a brush or other appliance should be passed through each tube. The examination can best be done by holding an electric lamp in the lower drum, and looking through the tubes from the upper drum or by passing an electric finger up the tubes. By this means any obstruction or corrosion becomes visible, and should scale or obstruction be found to exist, it should be at once removed. With the Yarrow type boiler, this offers no serious difficulty because the tubes are usually straight.

Preservation when Lying Up.—If the boiler is intended to lie up for a lengthened period, some quicklime in suitable trays should be put into the lower and upper drums. The drums should then be closed up to exclude the air, care being taken to remove the lime before again filling the boiler with water. The object of the quicklime is to absorb any moisture that might remain in the interior of the boiler.

Another reliable practice when laying up a boiler is, after it has been thoroughly washed out, to close up all the manhole and mudhole doors, and to quite fill the boiler with clean water, adding 9 lbs. of common washing soda or 1 lb. of lime to each ton of water, the soda being dissolved in water before it is put in the boiler. Care should be taken before again starting the boiler under steam to thoroughly empty it.

A paraffin flare lamp or electric heater should be provided, so as to keep the boiler at a temperature slightly in excess of that of the surrounding atmosphere, otherwise moisture may collect on the outside surfaces and cause deterioration. This is particularly important in summer time when the daily variation of temperature is greater and humidity of atmosphere is often sufficient to deposit dew.

Funnel Covers.—The funnel covers should be put on to prevent rain wetting the tubes and casings. The funnel covers should always be fixed when the vessel is not under steam.

Brickwork.—If the boiler is to lie up for a lengthy period, it is

very desirable that the brickwork should be removed and only replaced when required.

Raising Steam.—When it is intended to raise steam, the boiler should be filled with water to half-way up the gauge glass, and 1 lb. or 2 lbs. of ordinary lime per 1000 gallons should be added in the form of lime water. The lime water should be passed through a fine strainer. If possible steam should be raised slowly when the brickwork is new or recently repaired, but at other times steam may be raised more quickly. See that all boiler fittings and feed arrangements are in good working order whilst raising steam.

Water Pockets.—In the case of the large Yarrow boilers, the water pockets can be cleaned by means of mudholes, but for large repairs a bolted joint is provided. The joint is made with red lead, or in an emergency with asbestos, metallic, or klingerite sheeting $\frac{1}{16}$ of an inch thick. Before breaking this joint, the weight of the boiler should be carried on lugs provided for that purpose at each end of the lower tube plates. When remaking the joints of these water pockets, after having screwed the joints up as tightly as possible, steam should be raised to 10 lbs. per sq. inch to thoroughly warm the boiler, and the bolts in the joints finally tightened up. It is only contemplated to break these joints in case of very important repairs.

Precautions when in Use.—When working, every opportunity should be taken to shut down each boiler in rotation in order to examine the brickwork and other parts of the boiler, and clean the tubes inside and out along with the remainder of the boiler. The two or three rows of tubes nearest the fire require more careful attention than those which are further from it. If any accumulation of sediment is found it should be removed before the boiler is started again, and the source of the deposit ascertained.

Stoking Boiler with Coal.—A thin even fire should be kept, taking care to keep the corners of the grate covered. The thickness of the fire is to a great extent determined by the class of fuel used, and the amount of forcing adopted, but in any case flame should not be seen coming from the funnels, as that is a sure indication that the gases have not been properly burned. On the average, a thickness of fire from 5 to 6 inches has been found, with Welsh coal, to be suitable when working at $\frac{1}{2}$-inch air pressure. When working at 3 inches air pressure the thickness of the fire may be increased to 9 inches. The fire-doors should be open as little as possible when firing, so as to avoid cooling the furnace. In the best practice, the door is opened and shut between each shovelful.

When charging the furnace the coal must be thrown on the exact

places where required, and not piled up on the front end of the grate and afterwards pushed back, as is customary with ordinary marine boilers. With the aid of coloured glasses, the firemen can see where the holes in the fire are before they begin firing.

Feed Regulation.—In regulating the feed, the check valve should be altered very little at one time. Careful adjustment is required at first, and when once set to a suitable area of opening, little further attention is required.

Oil in Boiler.—No oil should be allowed to get into the boiler. If any oil is used for the internal lubrication of the machinery, it should be mineral oil, and generally it can be found that oil can be dispensed with altogether, which is very desirable. If reciprocating engines are installed, as little oil as possible should be used for lubricating the piston rods, because a certain amount of the oil invariably finds its way into the interior surfaces by this means.

Auxiliary Engines.—Special care should be taken that auxiliary engines are not of such a character as to involve the use of oil for internal lubrication. The auxiliary engines should be run without any internal lubrication whatever, and if any lubricators are fitted they should be removed.

Feed Filter.—An ample area feed filtering surface should be provided, and care taken to keep the material used clean.

Alkaline Water.—The water used in the boiler should always be pure, and only when unavoidable should it be obtained from a doubtful source on shore, as that will often lead to the formation of scale and corrosion. Tests should be made from time to time to ascertain that there is no acid contained in the water of the boiler, and not only should it be alkaline, but it must be definitely so. For this purpose 1 lb. to 2 lbs. of ordinary lime per thousand gallons should be pumped daily into the feed as milk of lime, or more if found necessary to ensure the water being decidedly alkaline. Care should be taken that connections between the boiler and water gauges are kept clear from any accumulation of lime.

Sea Water.—No sea water on any account should be allowed to get into the boiler, and for this reason care must be taken that the condensers are tight, that the evaporator does not prime, and that all sea connections are properly shut. If, however, sea water does get into the boiler, double the quantity of lime should be used with the feed, the fires must not be forced, and the density kept as low as possible.

Ash-pits and Fire-doors.—The ash-pit doors of boilers burning coal must always be kept properly working, so that in the event of a

boiler tube bursting, or steam suddenly escaping through any other cause, it may not find its way into the stokehold. For the same reason the fire-doors should be kept closed, except when stoking. In the event of a serious leakage of steam in the stokehold, the fan should be immediately turned on to force the escaping steam up the funnel, the stokehold doors should be closed, and the feed pumps turned on full speed.

Casing Joints.—The casing joints and doors must all be perfectly tight, because leakage of air will cause rapid destruction of the casings as well as loss in efficiency, and care must be taken not to allow any large accumulation of ashes or soot in any portion of the casing.

Tube Plugs.—In the event of a tube giving way, the ends should be closed by means of plugs. No appreciable reduction of efficiency would be found, even if after lengthened service 10 per cent. of the tubes are inoperative.

Gas.—When opening the boilers or any parts connected to them, such as cylinders, pipes, condensers, etc., great care must be taken to prevent any open light being near, as sometimes explosive gases are formed by the zinc in the boilers which may catch fire and cause serious injury unless every part is well ventilated.

Legislation on Steam Boilers.

The Boiler Explosions Act, 1882 (45 and 46 Vict., cap. 22) and 1890 (53 and 54 Vict., cap. 35), provide for inquiry into boiler explosions, and the Factory and Workshop Act, 1901, deals with the upkeep and inspection of all steam boilers.

The whole of the United Kingdom is included in the Acts, and the term "boiler" means any closed vessel used for generating steam, heating any liquid, or receiving steam for heating, steaming, or boiling, excepting boilers used exclusively for domestic purposes or in service of His Majesty.

On the occurrence of an explosion to a boiler, notice should be sent within twenty-four hours to the Board of Trade by the owner, user, or person acting for him. This notice must state the name of the premises or works, postal address, day and hour of explosion, number of persons killed and injured, description of boiler, purpose used for, particulars of failure, working pressure, by whom last inspected, and by whom insured.

The Board of Trade will then appoint a court to hold a preliminary inquiry by competent persons, and afterwards, if considered expedient, a formal investigation, with powers to inspect any premises, summon attendances of witnesses, enforce production of documents,

allow expenses and impose costs of either preliminary inquiry or formal investigation. The court will report to the Board of Trade, with any observations, and this report is printed and distributed.

The Act of 1890 makes the Act of 1882 applicable to boilers used on ships and in mines, with the exception of those used in His Majesty's Service.

The Act of 1901 is far more stringent than the preceding Acts and compels every steam user to have the boilers regularly examined by a competent person. Clause II. (*b*) states that the boiler is "to be examined thoroughly by a competent person at least once every fourteen months," also that the boiler must "have attached to it a proper safety valve and a proper steam gauge and water gauge to show the pressure of the steam and the height of water in the boiler".

Every boiler, safety valve, steam gauge, and water gauge must be maintained in proper condition, and a report of the result of every such examination in prescribed form, containing the prescribed particulars, shall within fourteen days be entered into or attached to the general register of the factory or workshop, and the report must be signed by the person making the examination, and, if that person is an inspector of a boiler inspecting company or association, it must also be signed by the chief engineer of the company or association.

THE END.

INDEX.

ABERDEEN : THE UNIVERSITY PRESS